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Endo et al.

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(45) **Date of Patent: Nov. 22, 2011**

(54) **COLOR SEQUENTIAL ILLUMINATION FOR SPATIAL LIGHT MODULATOR**

(75) Inventors: **Taro Endo**, Chofu (JP); **Kazuma Arai**, Hachioji (JP); **Yoshihiro Maeda**, Hachioji (JP); **Fusao Ishii**, Menlo Park, CA (US)

(73) Assignees: **Silicon Quest Kabushiki-Kaisha** (JP); **Olympus Corporation** (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **12/286,838**

(22) Filed: **Oct. 1, 2008**

(65) **Prior Publication Data**

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Related U.S. Application Data

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(51) **Int. Cl.**

G02B 26/00	(2006.01)
G02B 26/08	(2006.01)
G02F 1/29	(2006.01)
G02F 1/153	(2006.01)

(52) **U.S. Cl.** **359/292**; 359/298; 359/267

(58) **Field of Classification Search** 359/242, 359/290, 292, 298, 247, 267

See application file for complete search history.

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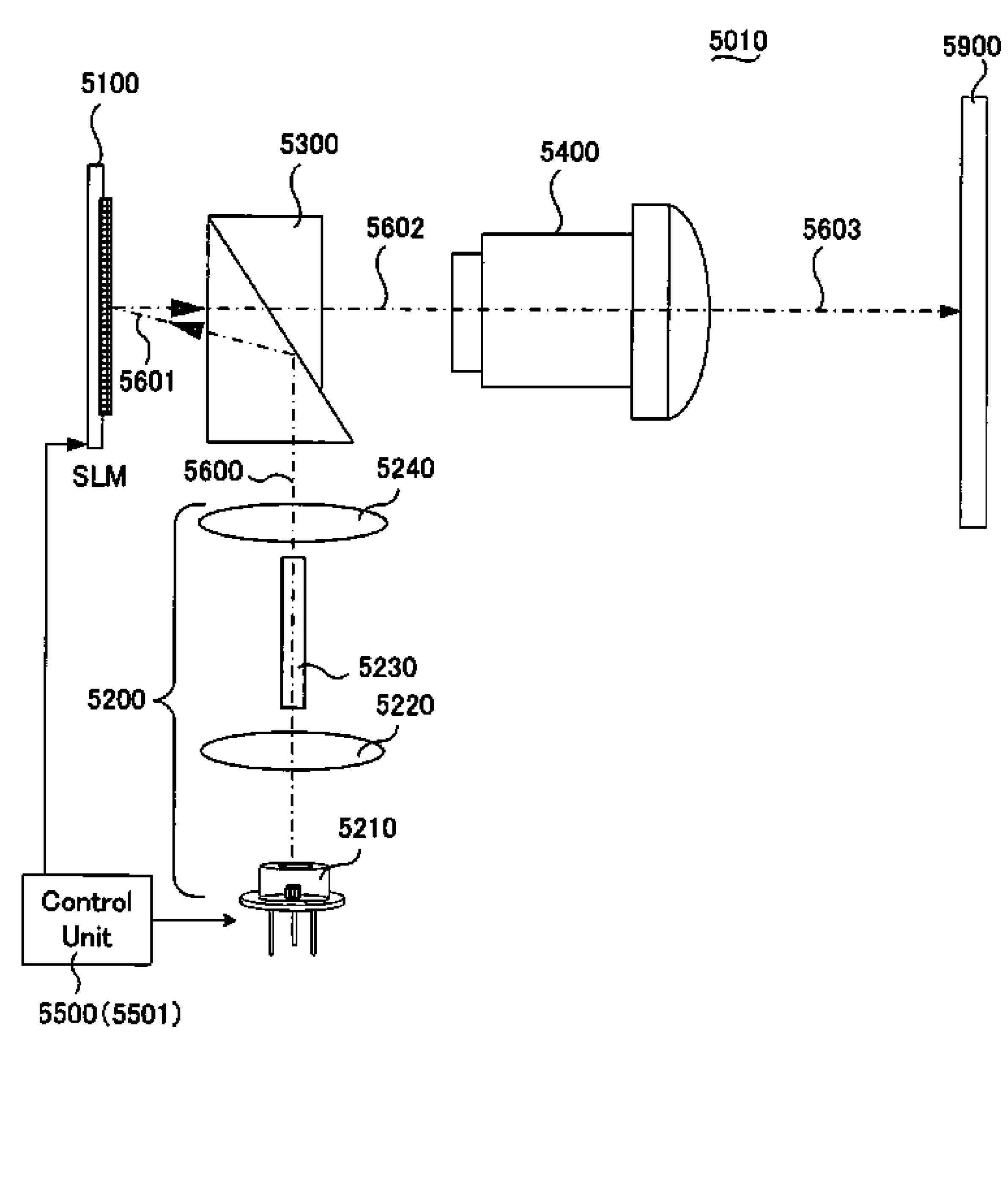
Primary Examiner — Ricky Mack
Assistant Examiner — Brandi Thomas
(74) *Attorney, Agent, or Firm* — Bo-In Lin

(57) **ABSTRACT**

The present invention provides a display apparatus, comprising: a light source or light sources for emitting a luminous flux or luminous fluxes having a plurality of colors; a spatial light modulator for modulating the luminous flux(es) having a plurality of colors incoming from the light sources; and controller for processing video image input data, which is input, and controlling the light source(s) and the spatial light modulator, wherein the controller generates a plurality of video image signals of colors constituting a video image based on the video image input data, and controls the light source(s) so as to cause the light source(s) having at least two colors, from among the light source(s) having a plurality of colors, to perform pulse emission in sequence and modulate the pulse emission during a period shorter than a modulation period controlled under the spatial light modulator is with the video image signal of one color from among the video image signals.

17 Claims, 26 Drawing Sheets



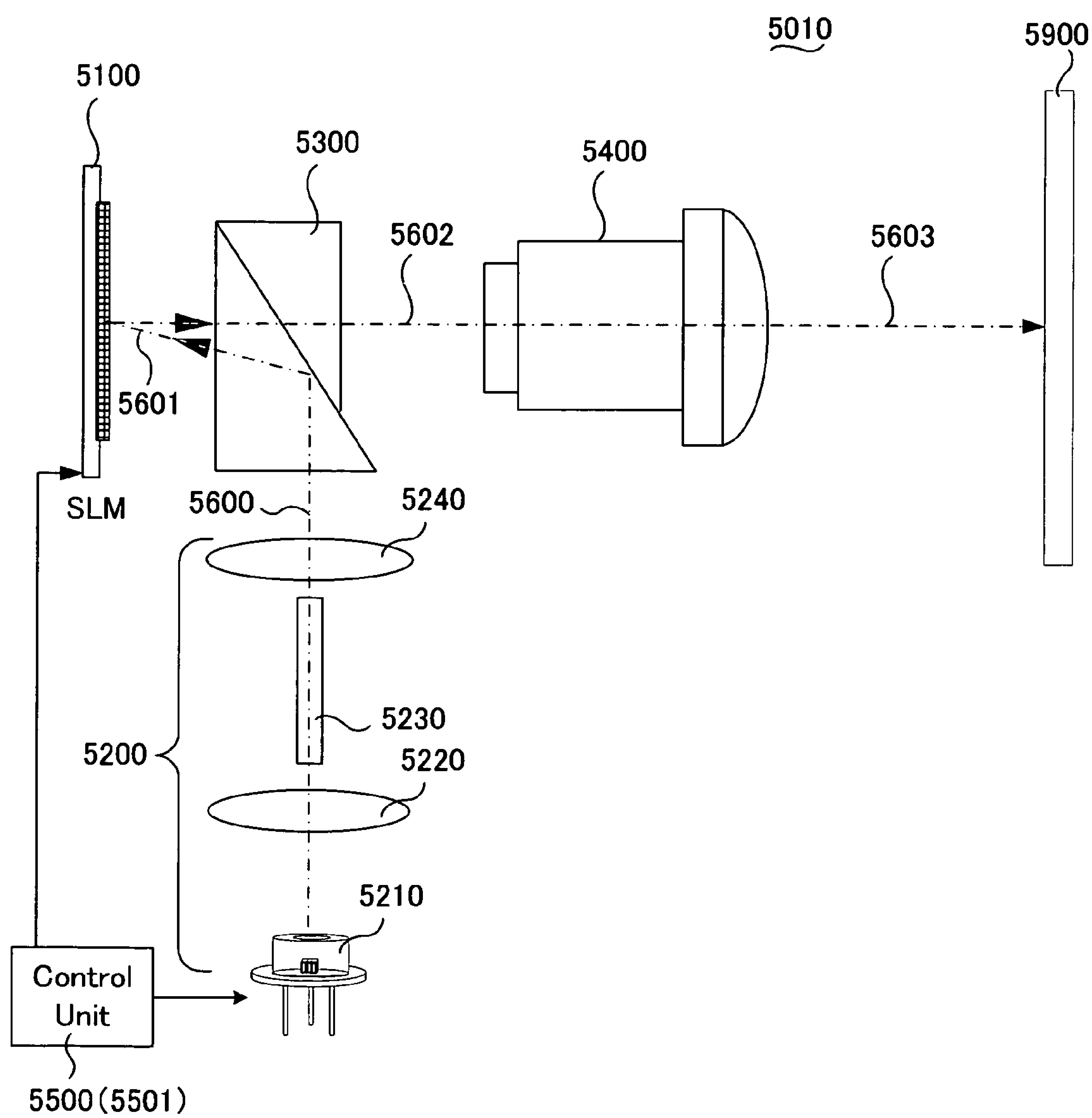

5010
5100
5900
5300
5400
5602
5603
5601
SLM
5600
5240
5230
5200
5220
5210
Control Unit
5500(5501)

FIG. 1

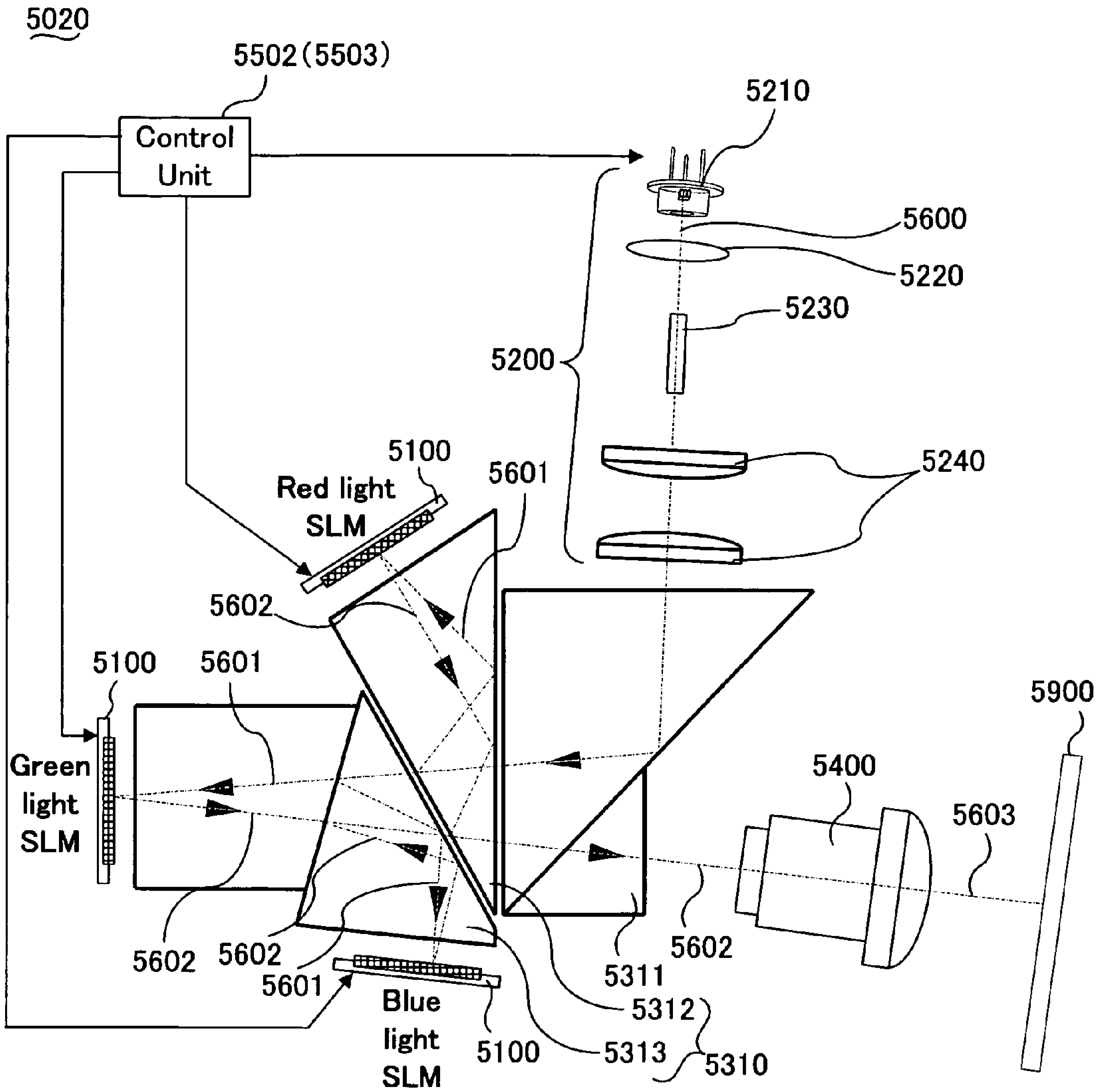

5020
5502(5503)
Control Unit
5210
5600
5220
5230
5200
5240
5100
Red light SLM
5601
5602
5100
5601
5900
Green light SLM
5400
5603
5602
5602
5601
Blue light SLM
5100
5311
5602
5312
5313
5310

FIG. 2

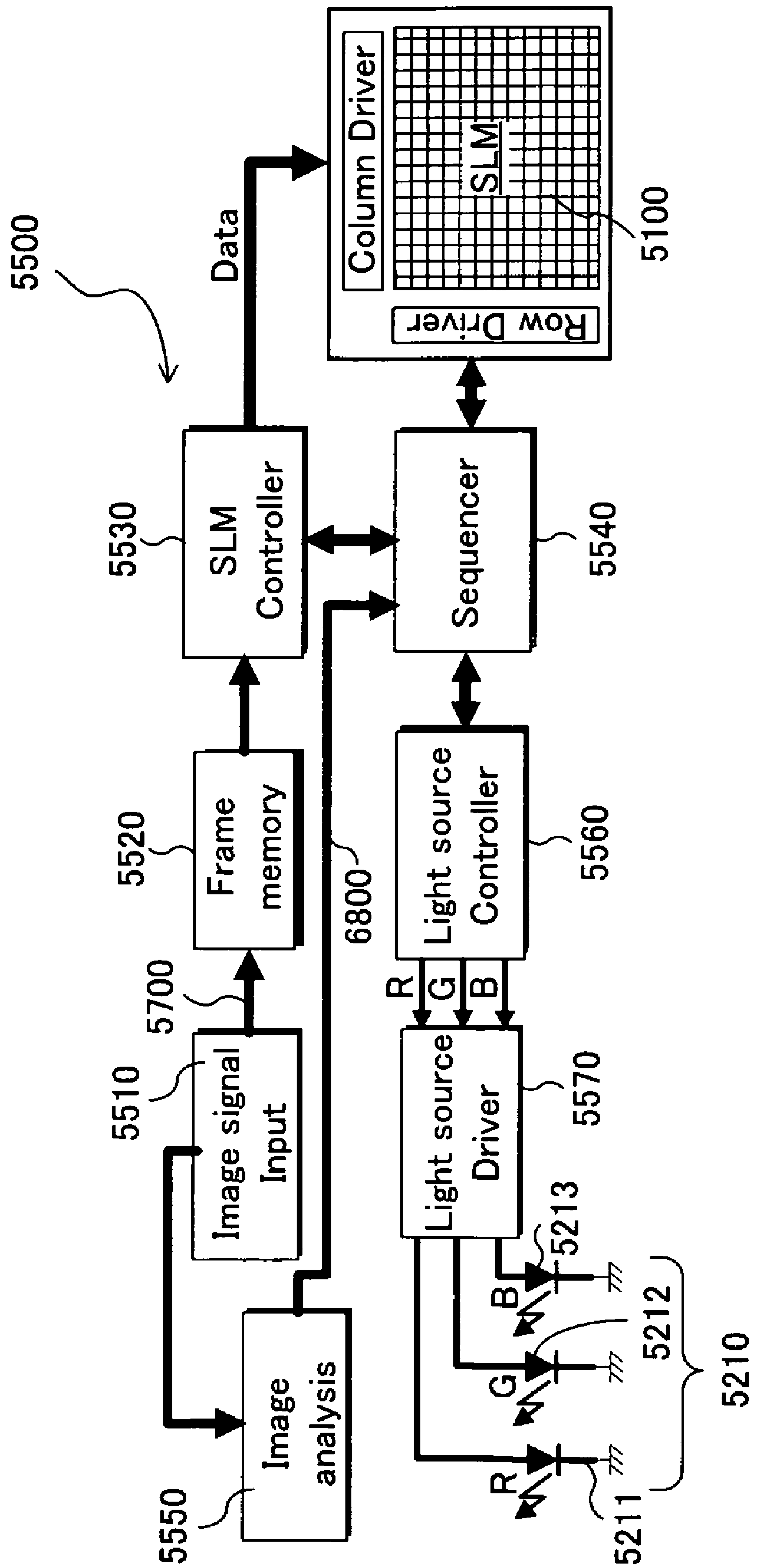

5500
Column Driver
SLM
Row Driver
5100
Data
SLM Controller
5530
Sequencer
5540
Frame memory
5520
Light source Controller
5560
6800
5700
Image signal Input
5510
R
G
B
Light source Driver
5570
Image analysis
5550
5213
5212
5211
5210

FIG. 3A

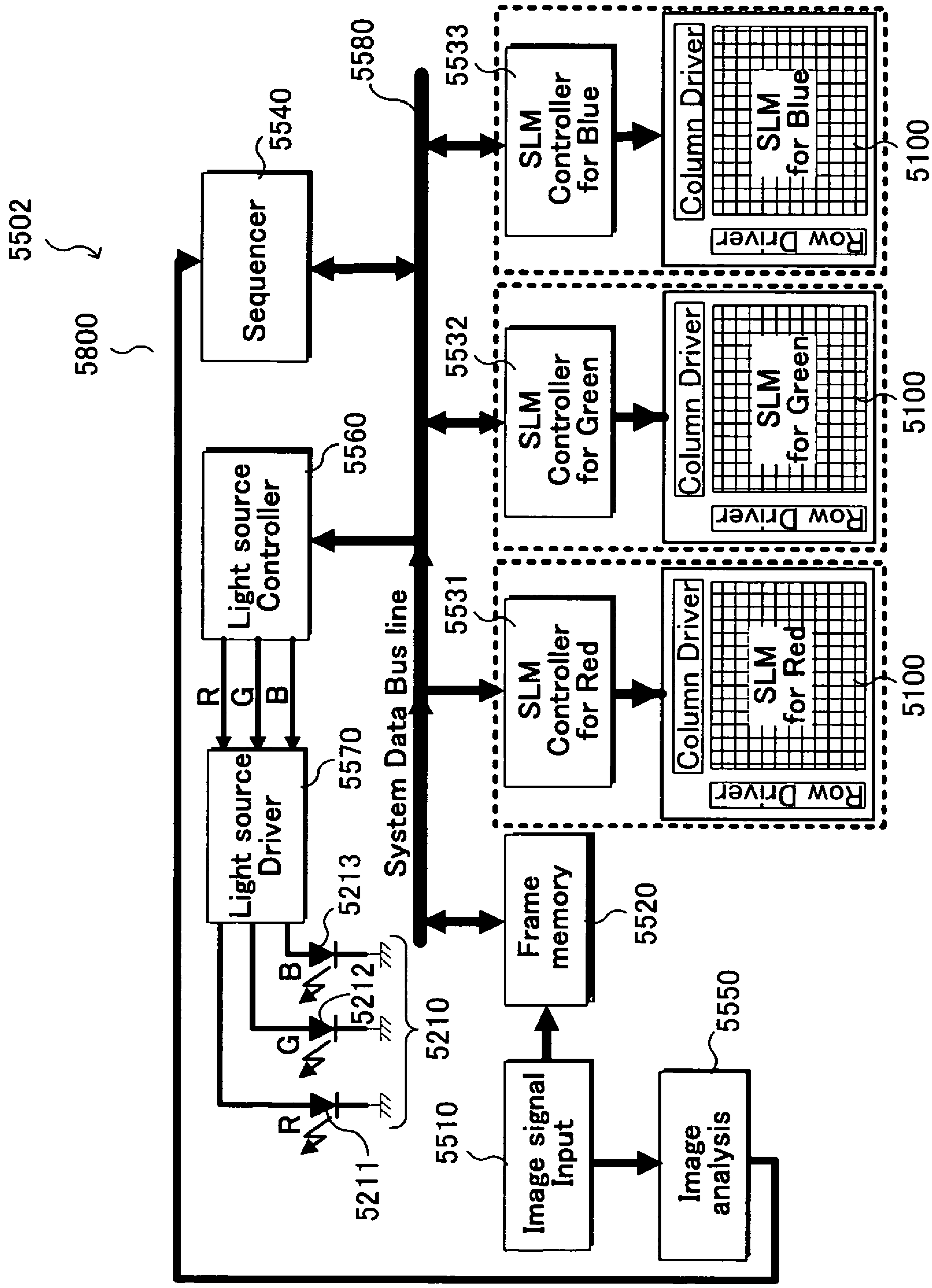

5502
5800
Sequencer
5540
Light source Controller
5560
5580
R
G
B
Light source Driver
5570
System Data Bus line
5213
5212
5211
5210
B
G
R
Frame memory
5520
Image signal Input
5510
Image analysis
5550
SLM Controller for Red
5531
SLM Controller for Green
5532
SLM Controller for Blue
5533
Column Driver
Row Driver
SLM for Red
SLM for Green
SLM for Blue
5100

FIG. 3B

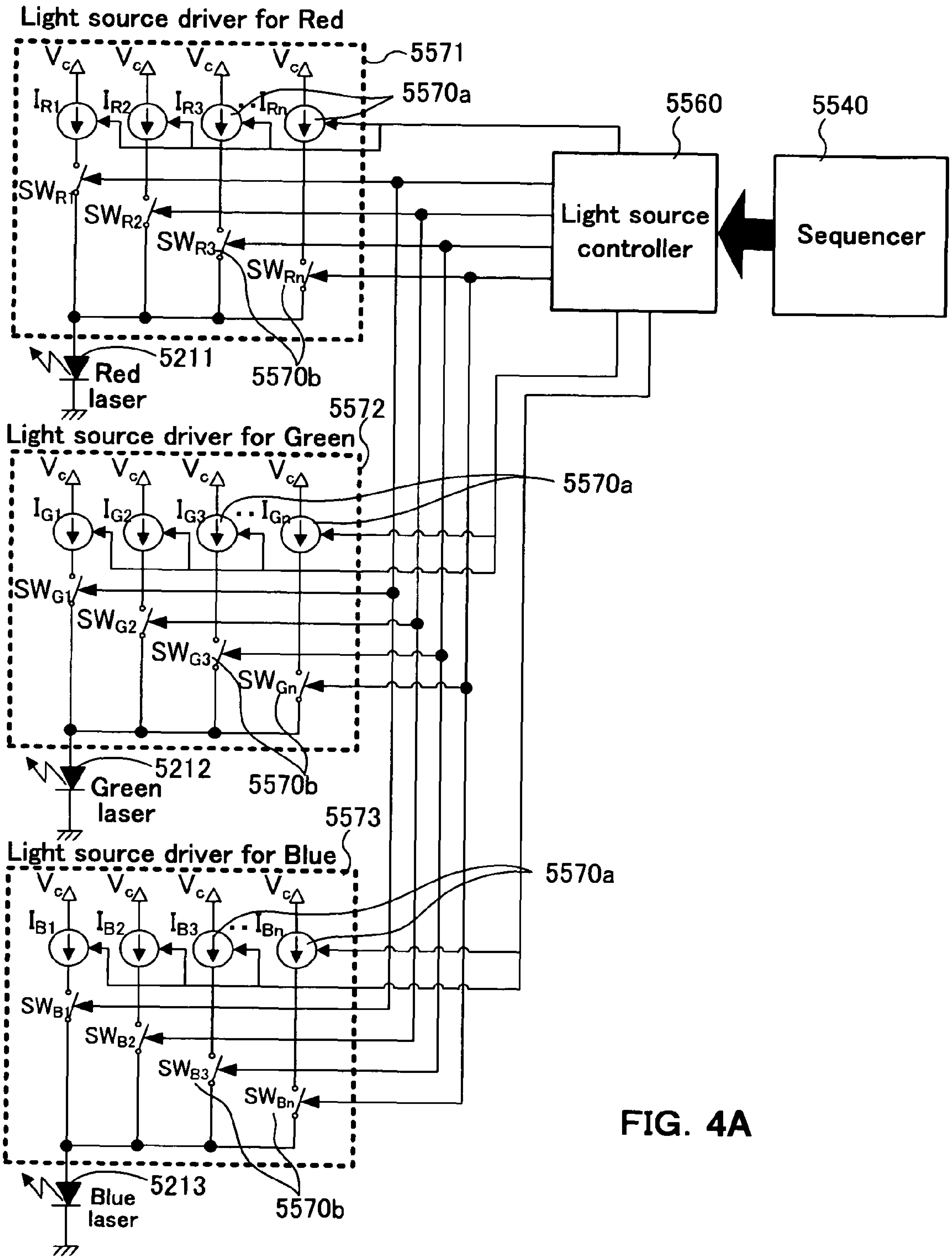
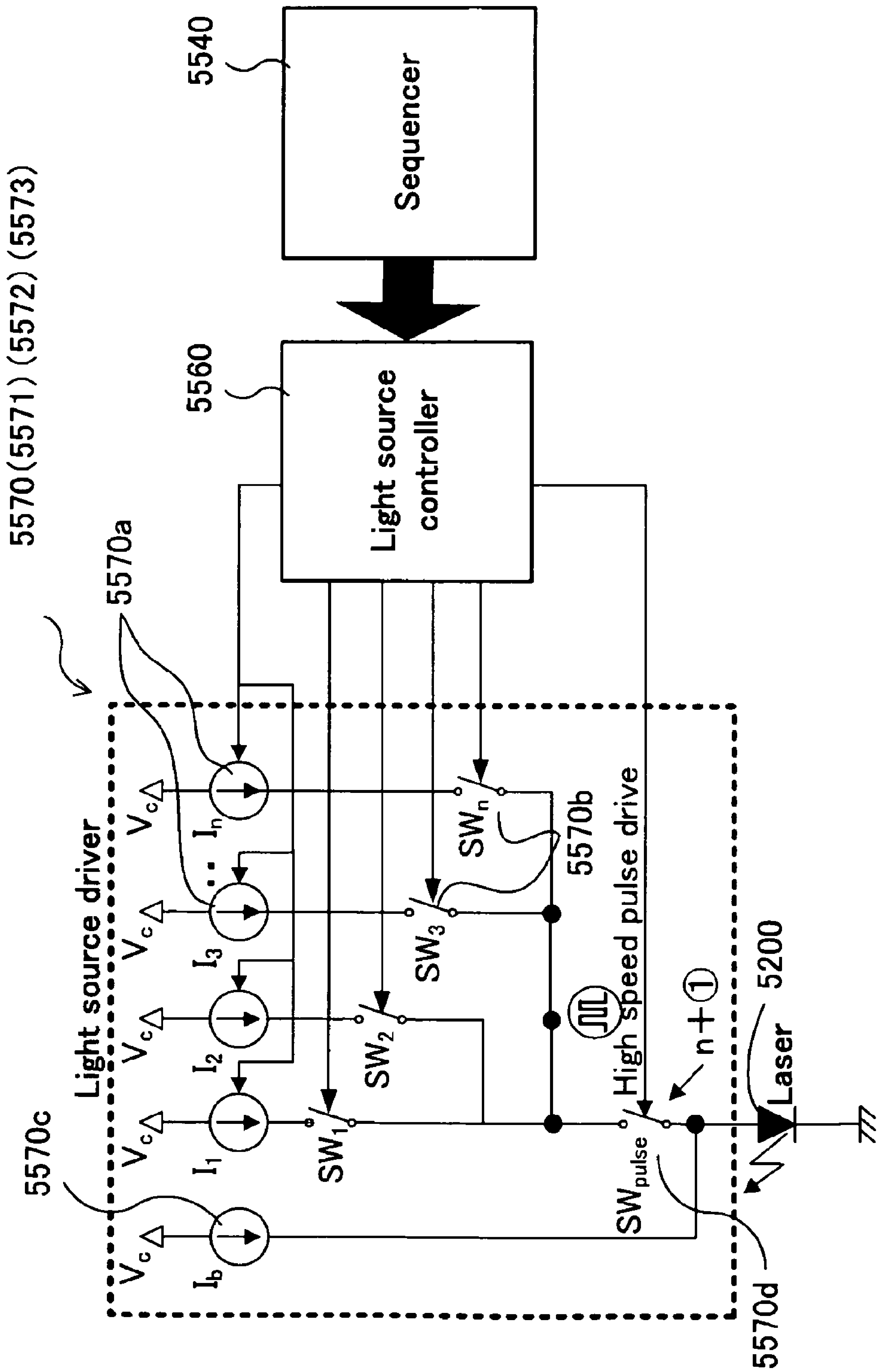

Light source driver for Red
5571
5570a
5560
5540
Light source controller
Sequencer
5211
Red laser
5570b
5572
Light source driver for Green
5570a
5212
Green laser
5570b
5573
Light source driver for Blue
5570a
5213
Blue laser
5570b

FIG. 4A



5540
Sequencer
5560
Light source controller
5570(5571)(5572)(5573)
5570a
Light source driver
5570c
Vc
Ib
I1
I2
I3
In
SW1
SW2
SW3
SWn
5570b
High speed pulse drive
n+1
5200
Laser
SWpulse
5570d

FIG. 4B

Gray scale N bit $\geqq$ n
I_1 = a first current for I_{th} and LSB
I_2 = a first current for LSB+1
I_3 = a first current for LSB+2
·
·
I_n = a first current for MSB

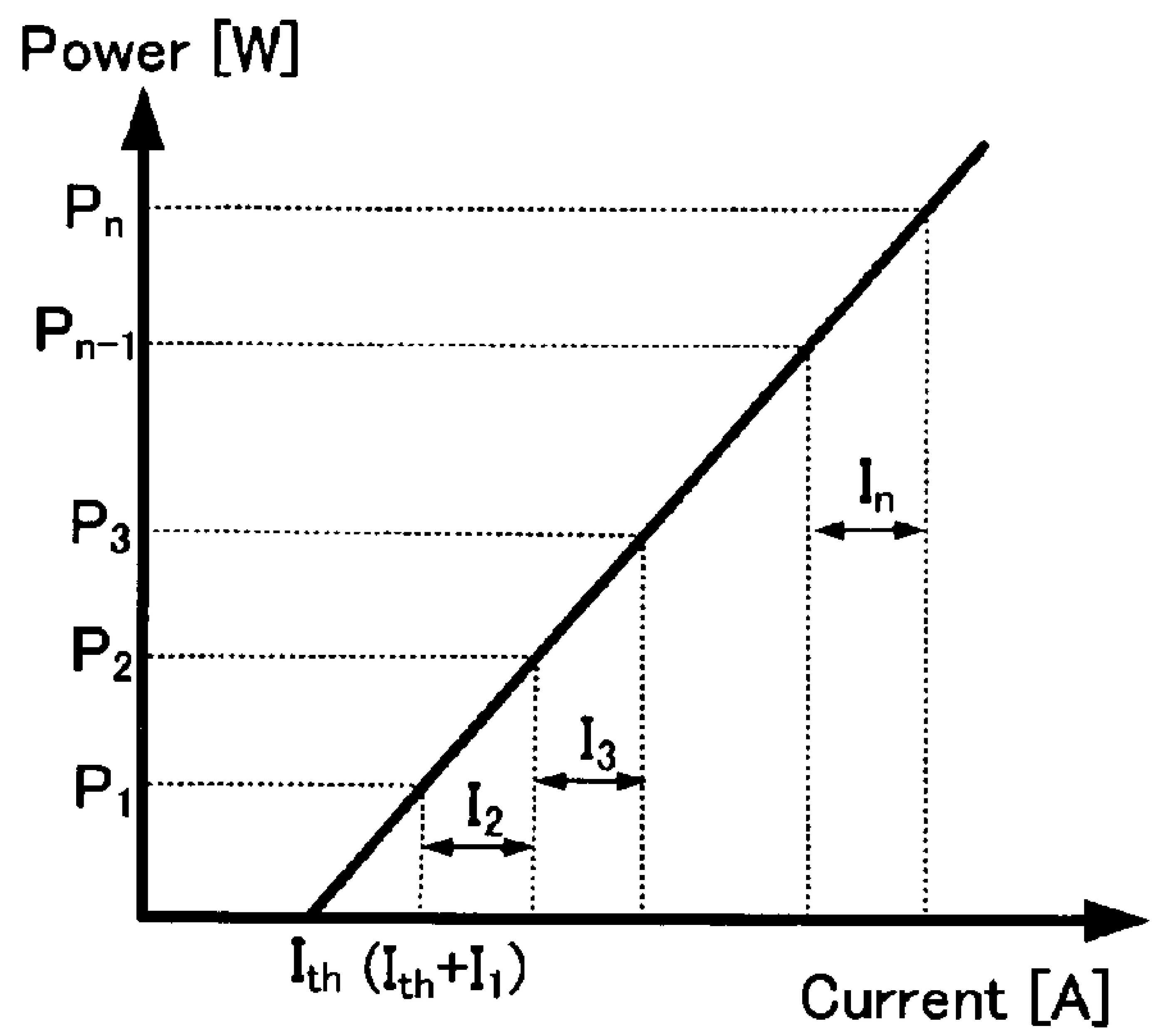


FIG. 5

$\cdot$non SW: $P_b = k \times I_b \fallingdotseq 0$ [mW] ($I_b \fallingdotseq I_{th}$)
$\cdot SW_1: P_1 = k \times (I_b + I_1)$
$\cdot SW_2: P_2 = k \times (I_b + I_1 + I_2)$
·
·
$\cdot SW_n: P_n = k \times (I_b + I_1 + I_2 + \cdots + I_{n-1} + I_n)$

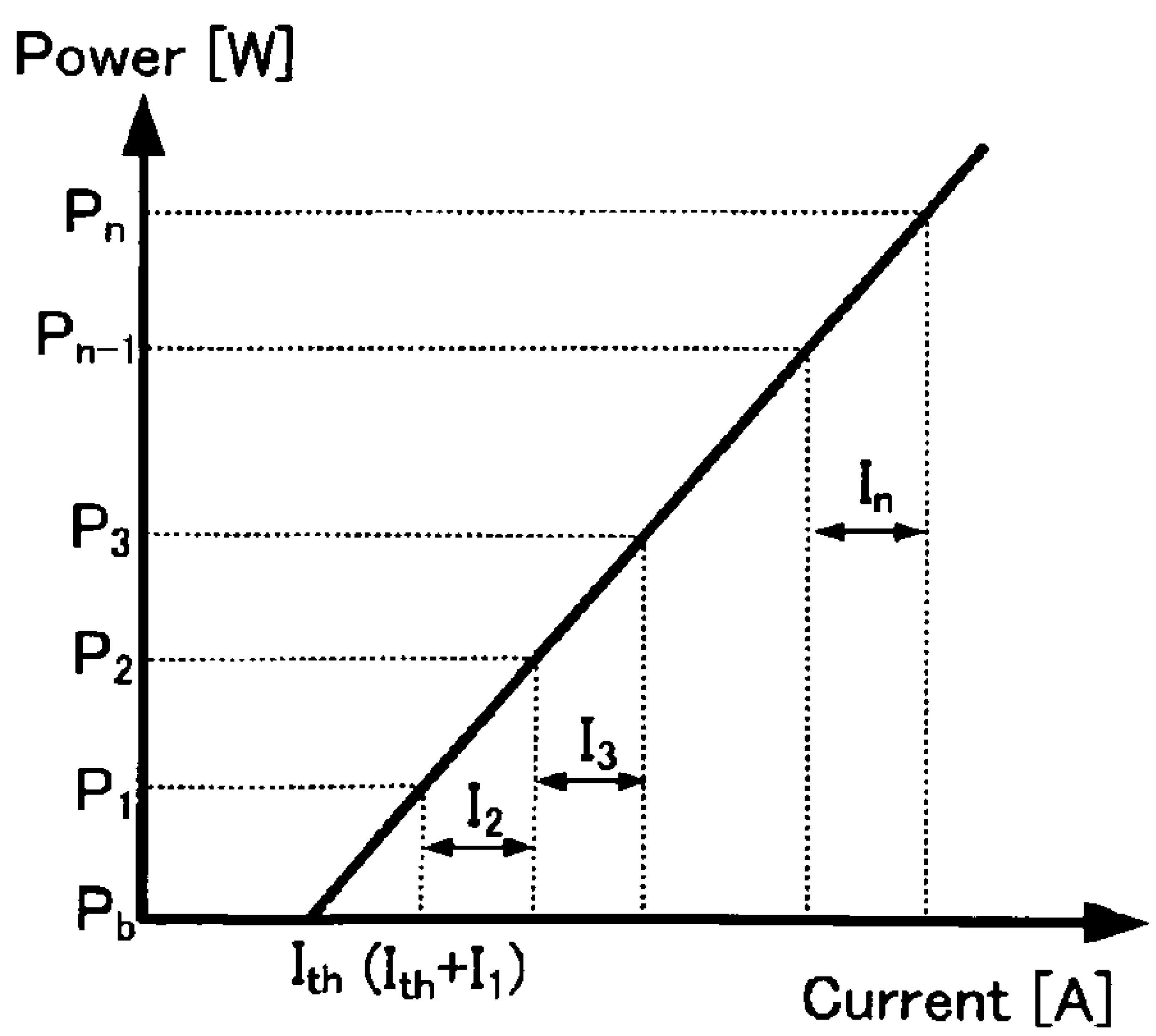


FIG. 6

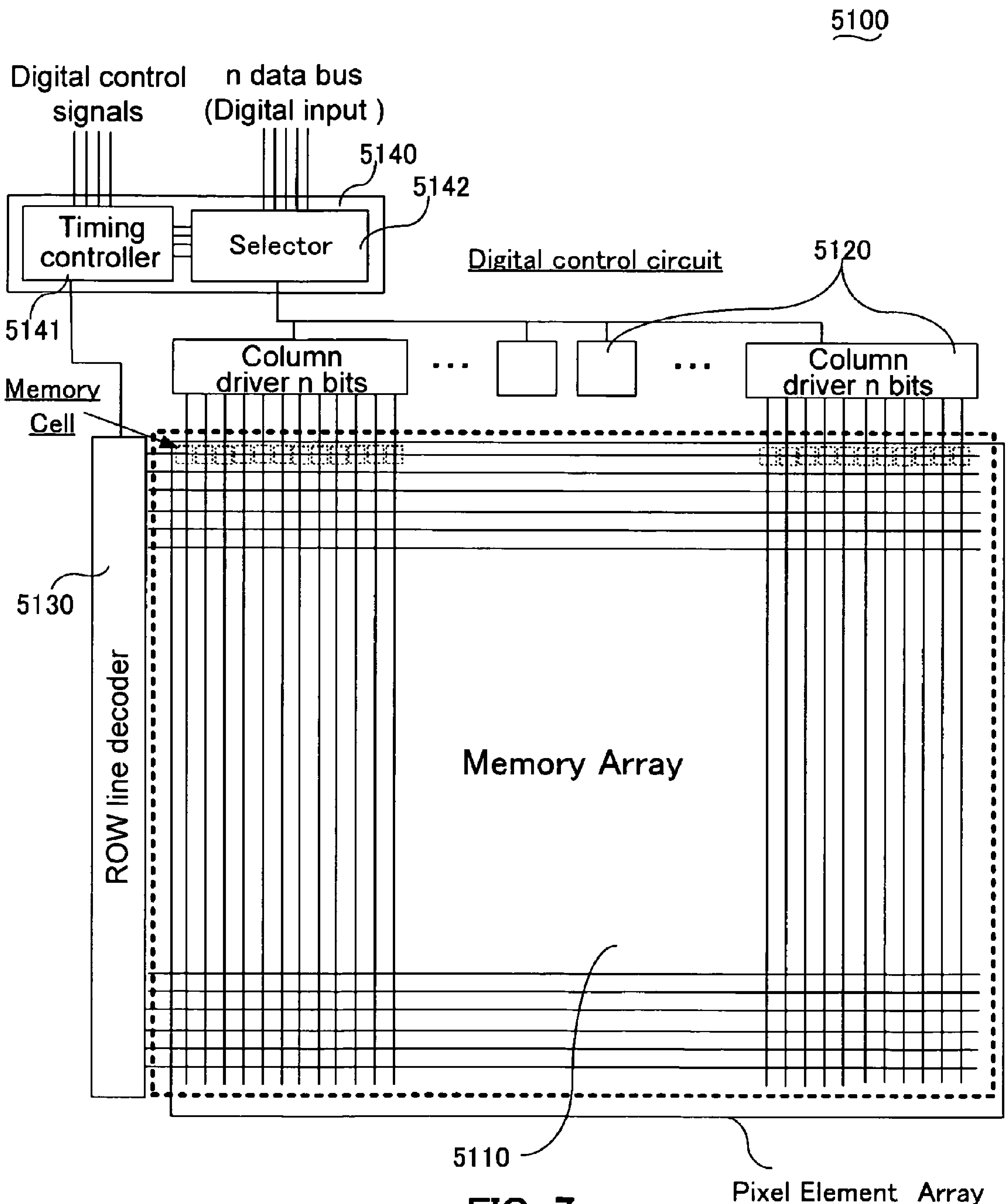

5100
Digital control signals
n data bus (Digital input)
5140
5142
Timing controller
Selector
Digital control circuit
5120
5141
Column driver n bits
Column driver n bits
Memory Cell
5130
ROW line decoder
Memory Array
5110
Pixel Element Array

FIG. 7

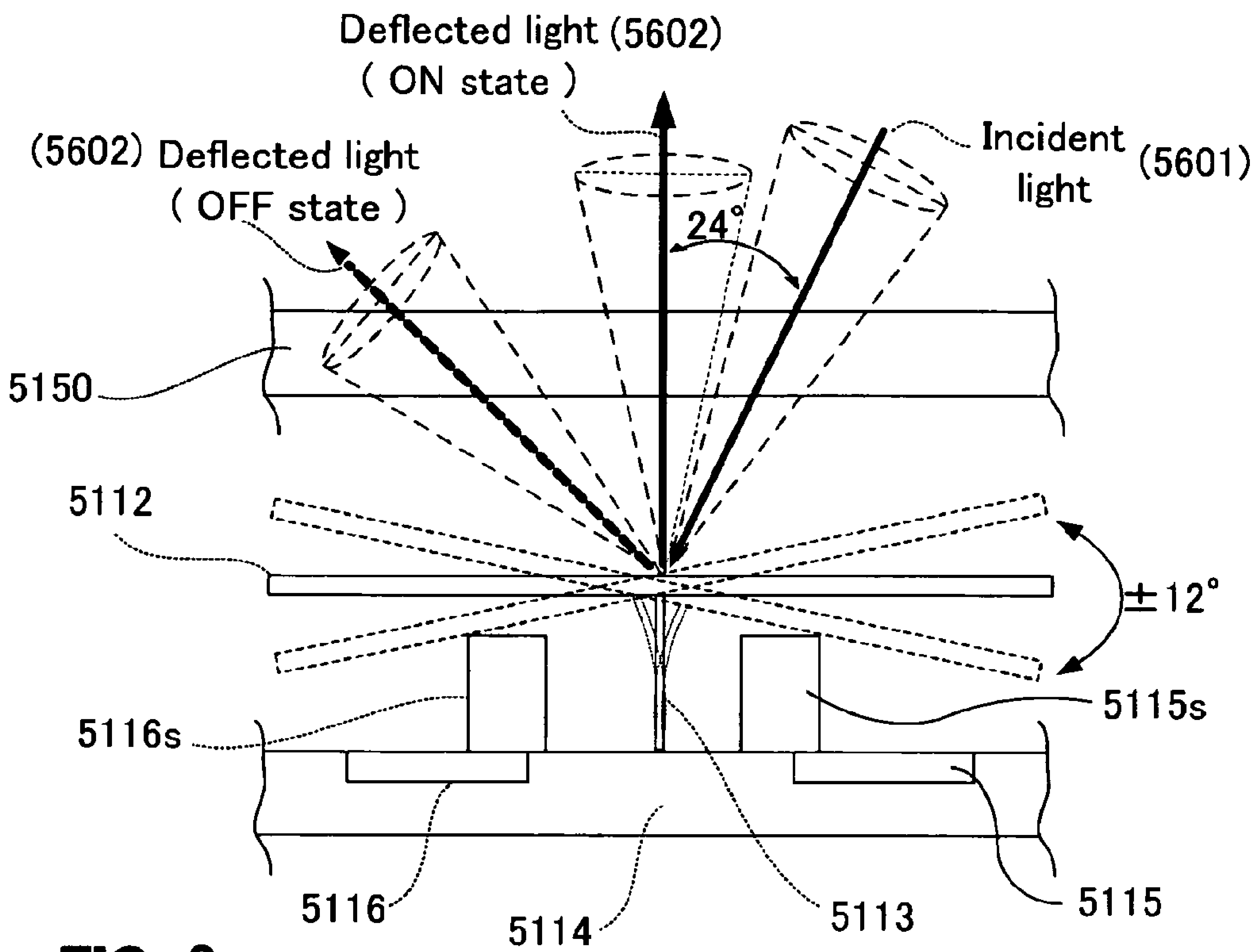

Deflected light (5602)
(ON state)
(5602) Deflected light
(OFF state)
Incident light
(5601)
24°
5150
5112
±12°
5116s
5115s
5116
5114
5113
5115

FIG. 8

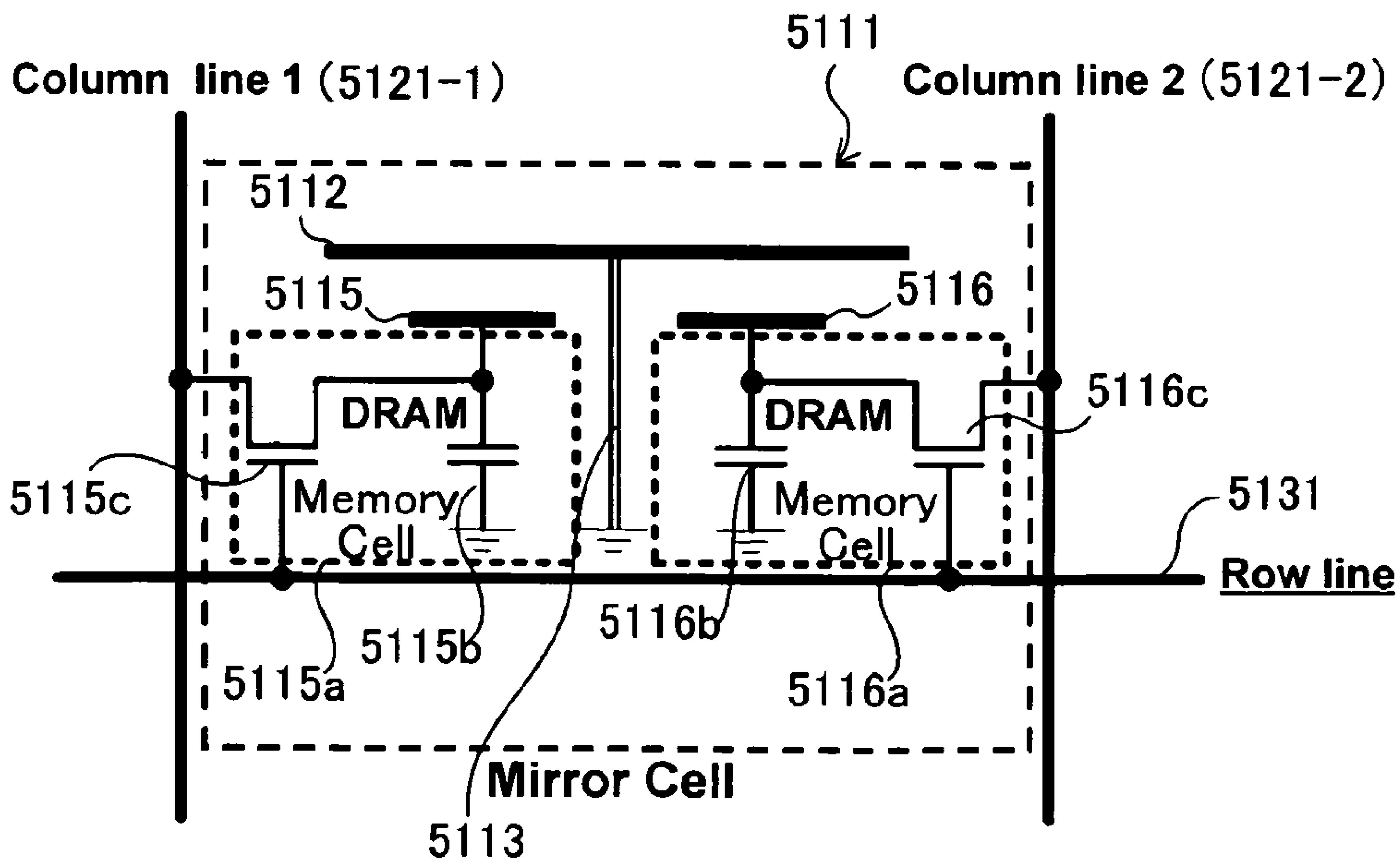

5111
Column line 1 (5121-1)
Column line 2 (5121-2)
5112
5115
5116
DRAM
DRAM
5116c
5115c
Memory Cell
Memory Cell
5131
Row line
5115a
5115b
5116b
5116a
Mirror Cell
5113

FIG. 9

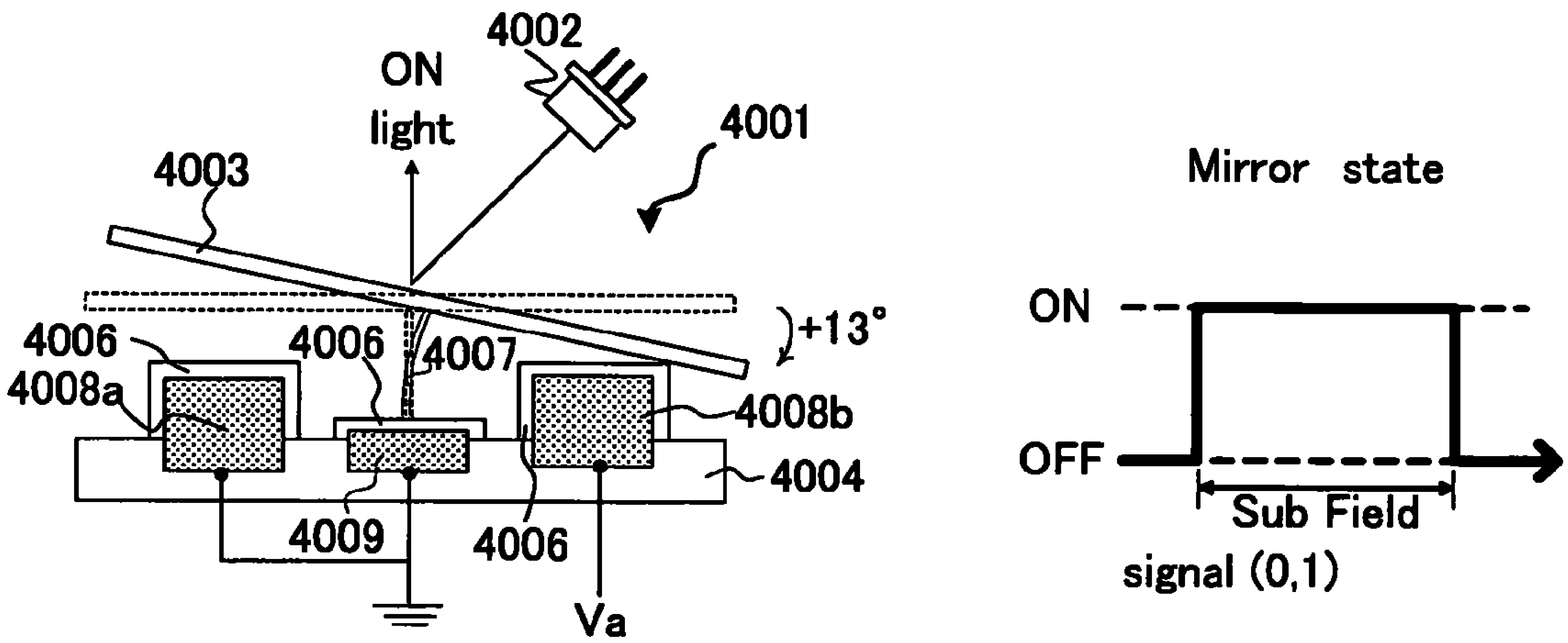


Fig.10A

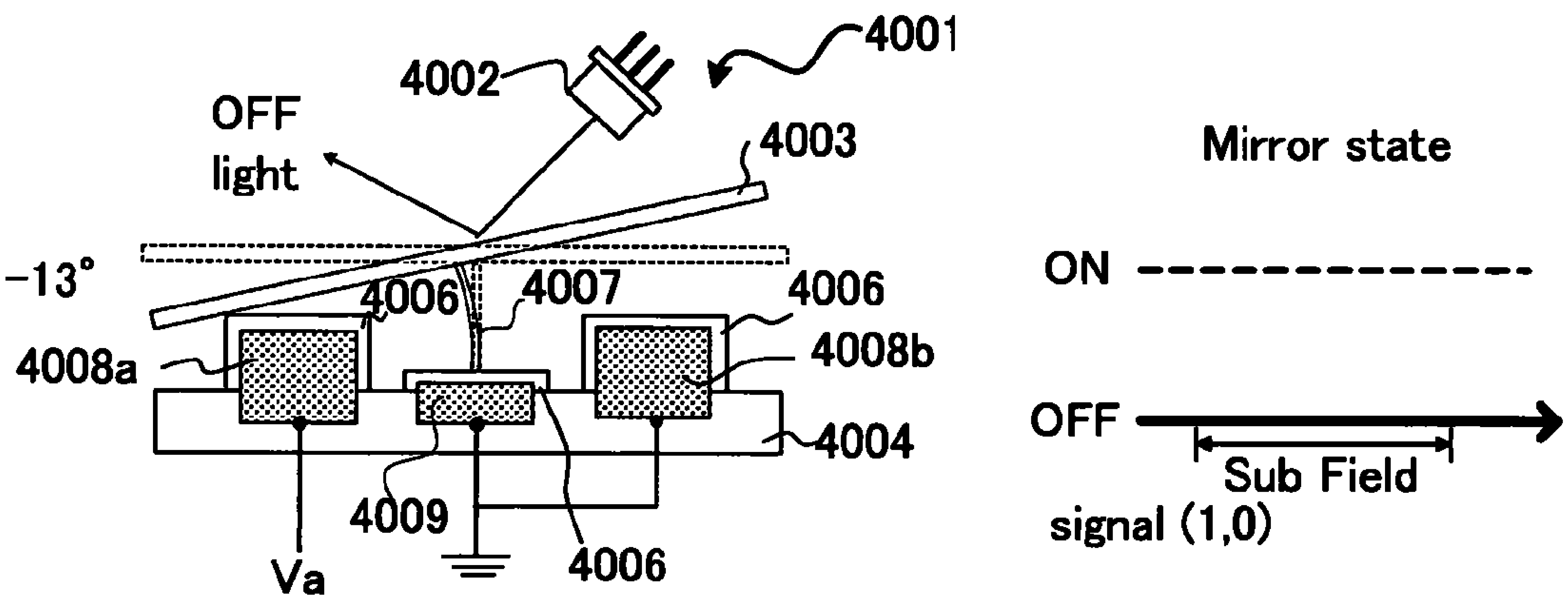


Fig.10B

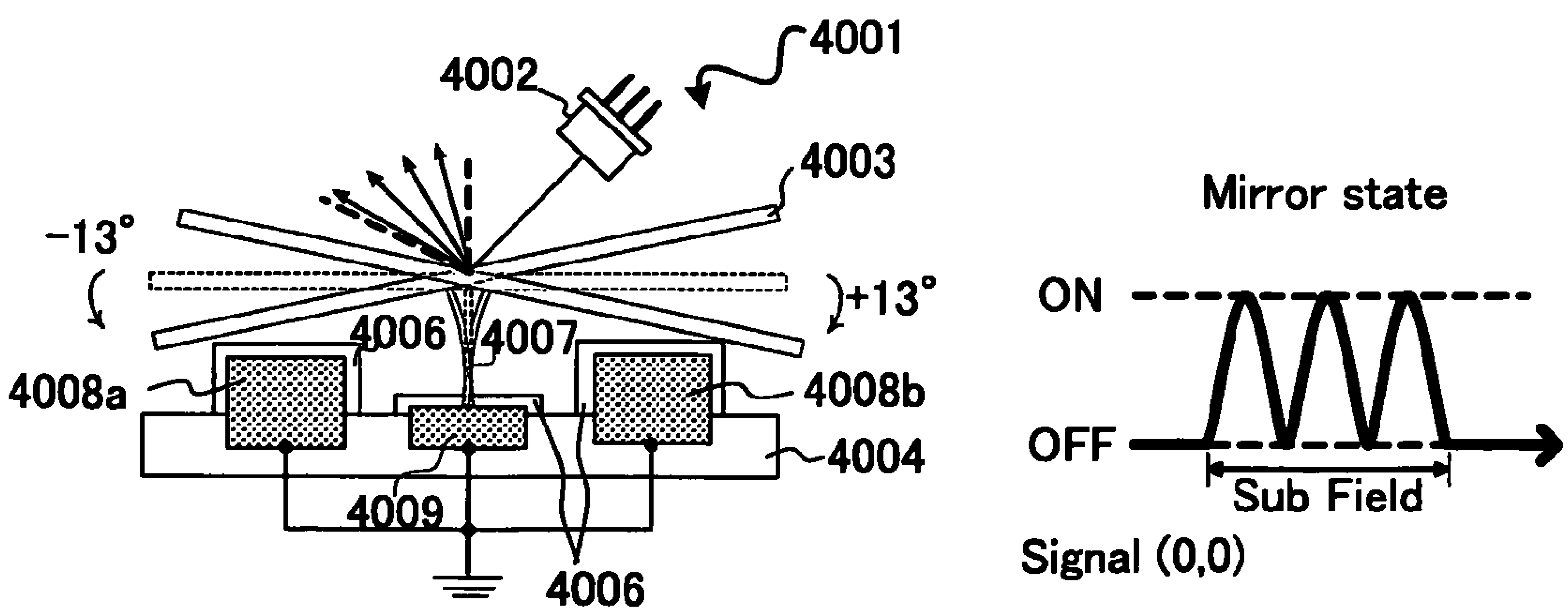


Fig.10C

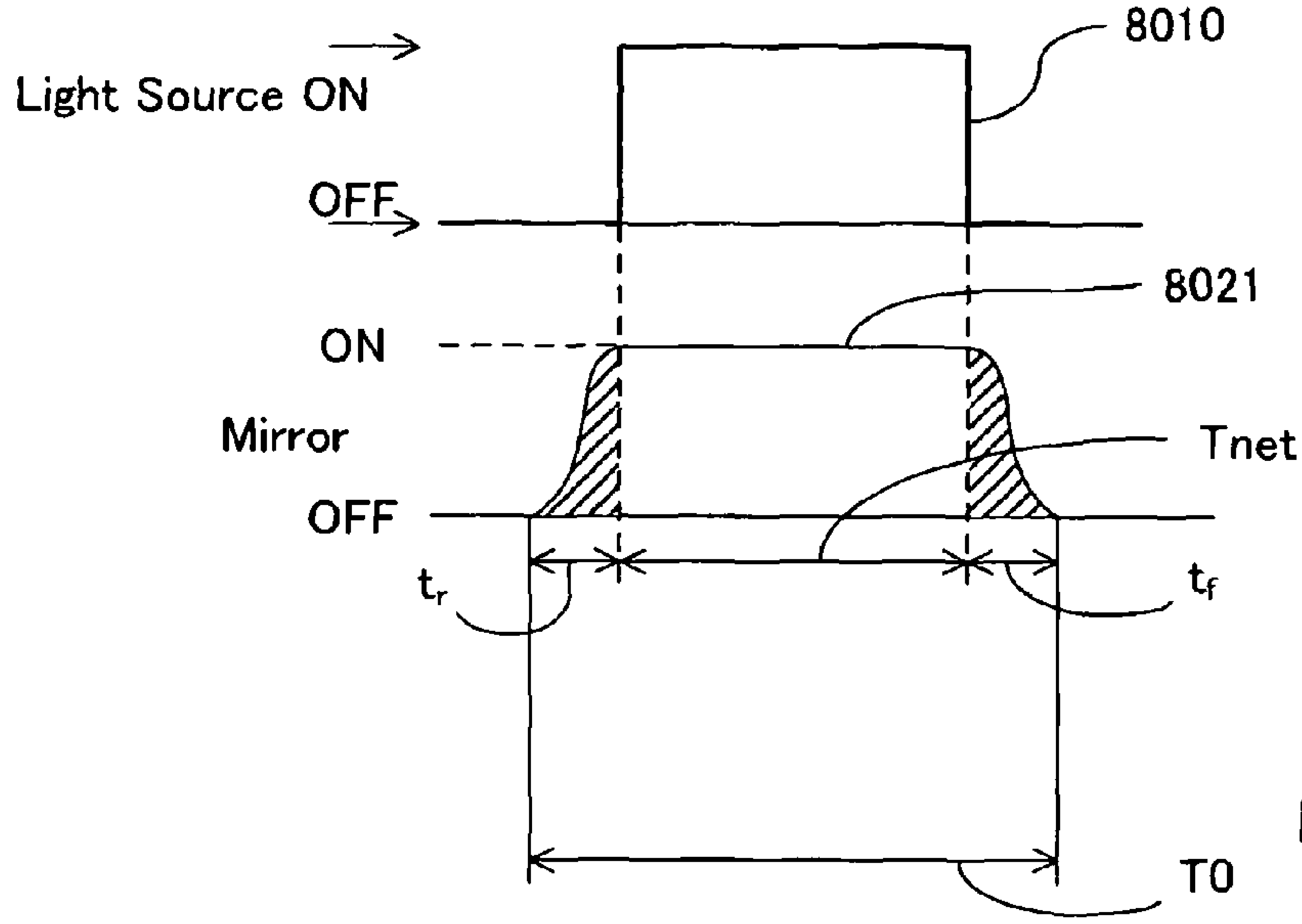

8010
Light Source ON
OFF
8021
ON
Mirror
OFF
Tnet
t_r
t_f
T0

FIG. 11

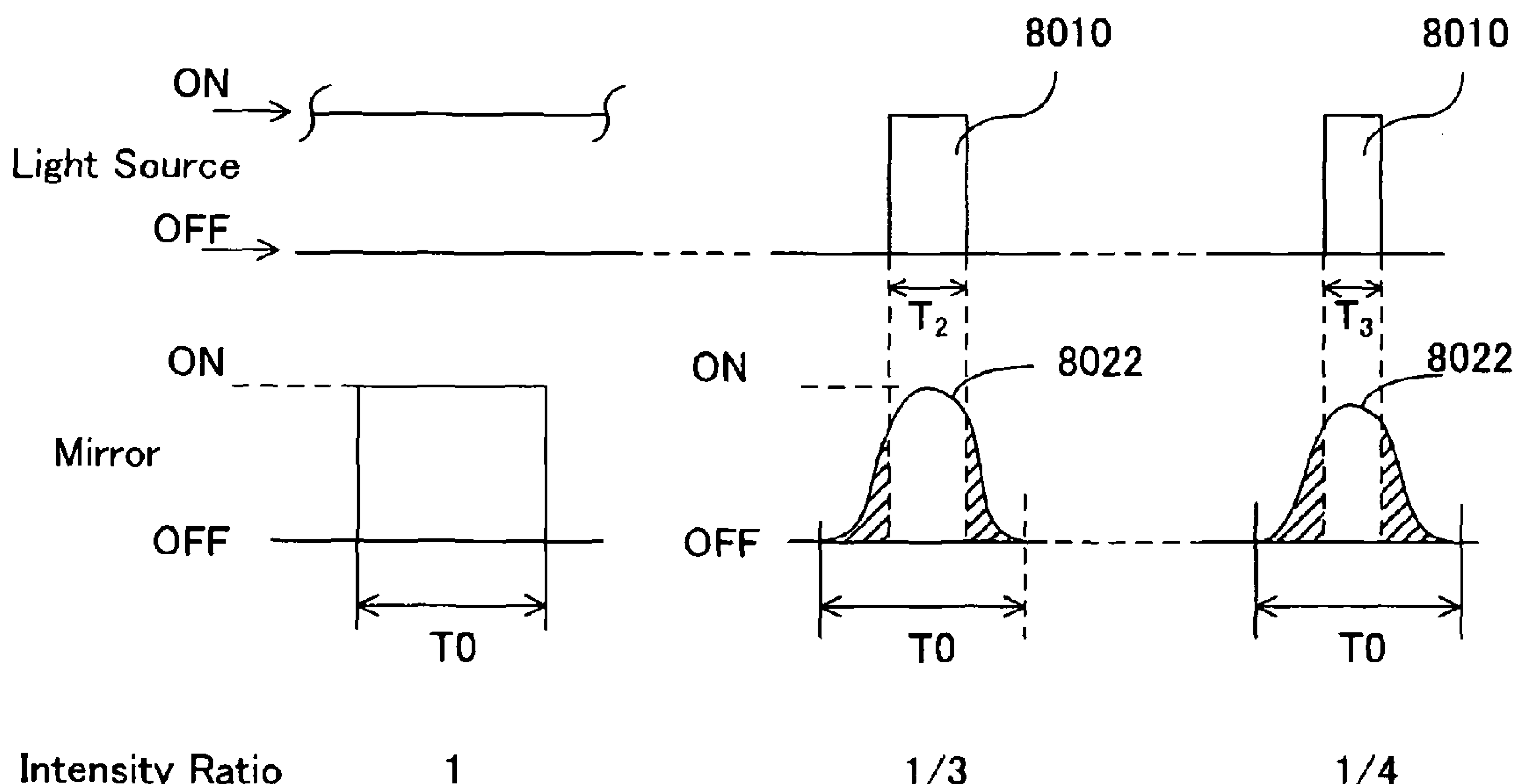
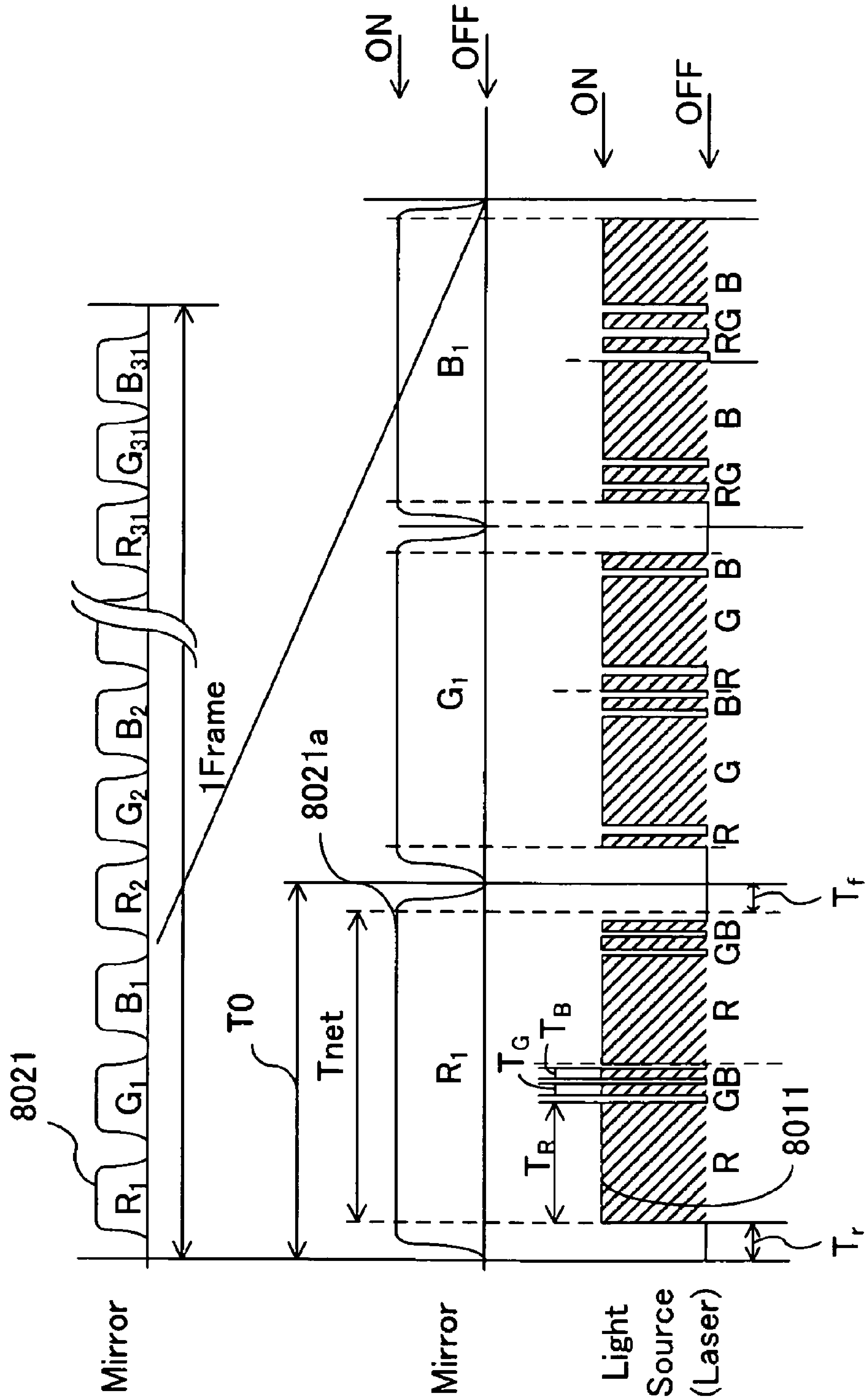
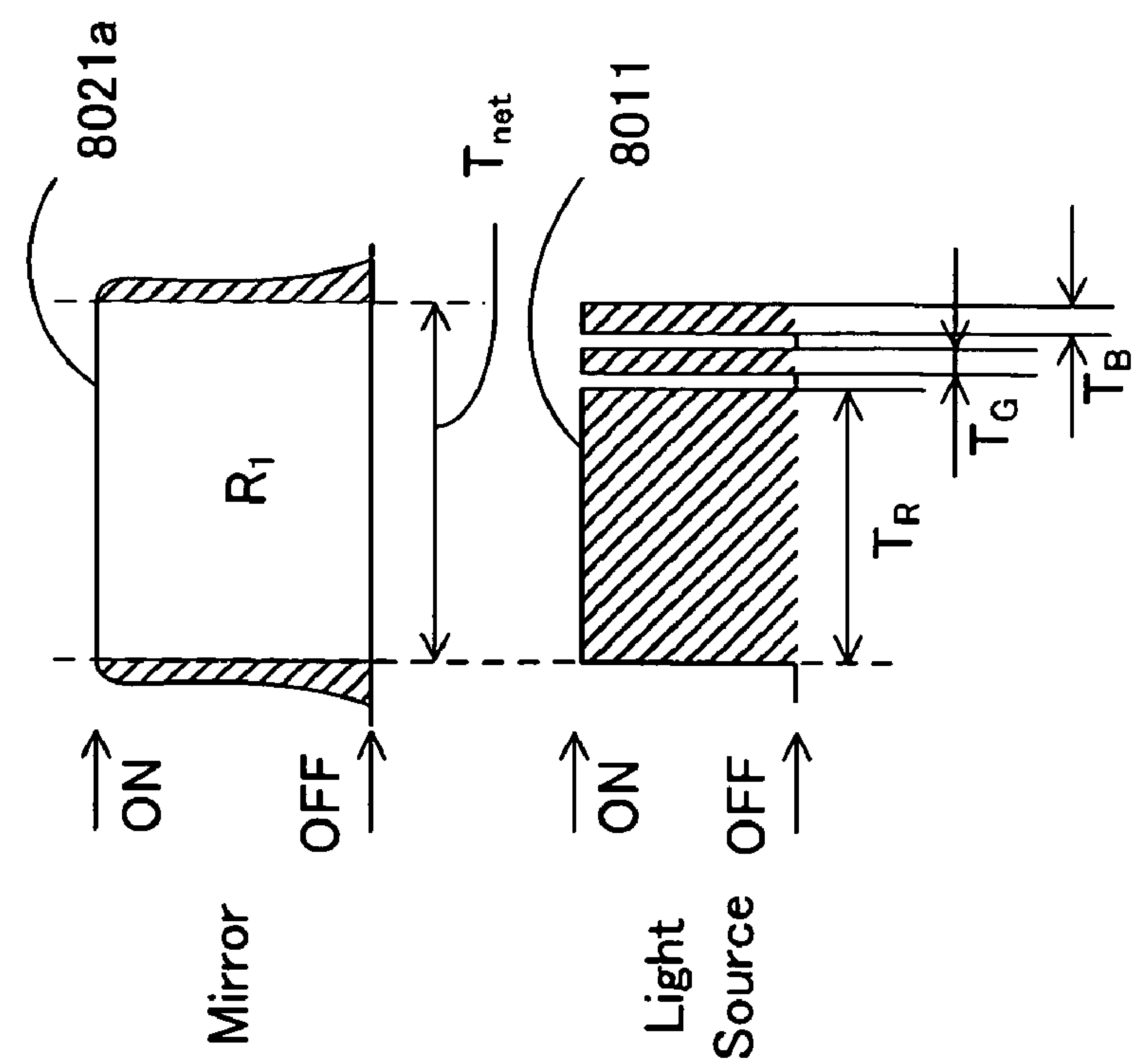

8010
8010
ON
Light Source
OFF
T_2
T_3
ON
ON
8022
8022
Mirror
OFF
OFF
T0
T0
T0
Intensity Ratio
1
1/3
1/4

FIG. 12



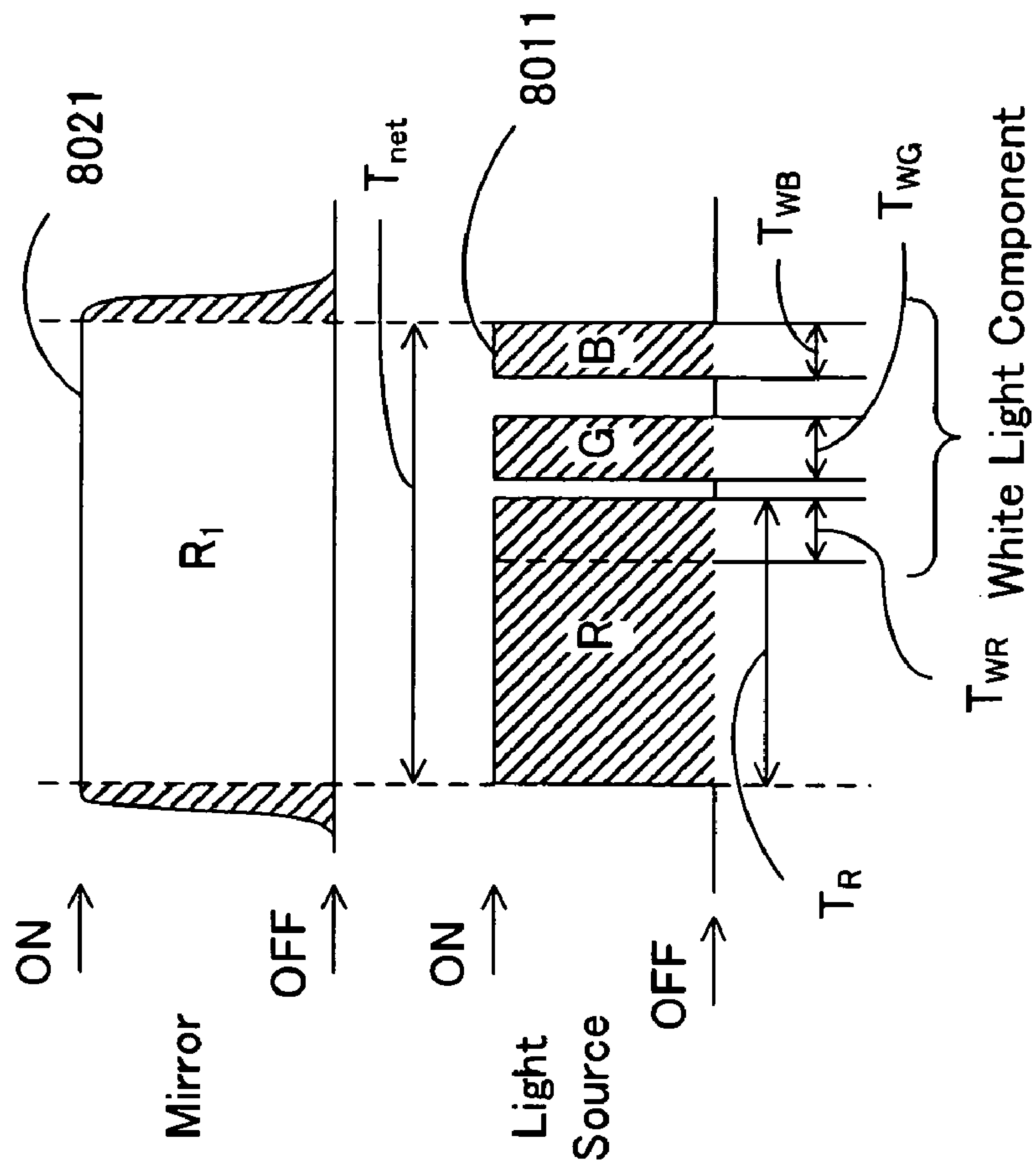
Mirror
Mirror
Light Source (Laser)
ON
OFF
ON
OFF
8021
8021a
8011
1Frame
T0
Tnet
T_B
T_G
T_B
T_f
T_r
R_1
G_1
B_1
R_2
G_2
B_2
R_{31}
G_{31}
B_{31}
R GB R GB R G B/R G B B RG B RG B

FIG. 13



8021a
R_1
T_{net}
8011
T_R
T_G
T_B
ON
OFF
ON
OFF
Mirror
Light Source

FIG. 14



8021
R_1
T_{net}
8011
B
G
R
T_{WB}
T_{WG}
White Light Component
T_{WR}
T_R
ON
OFF
ON
OFF
Mirror
Light Source

FIG. 15

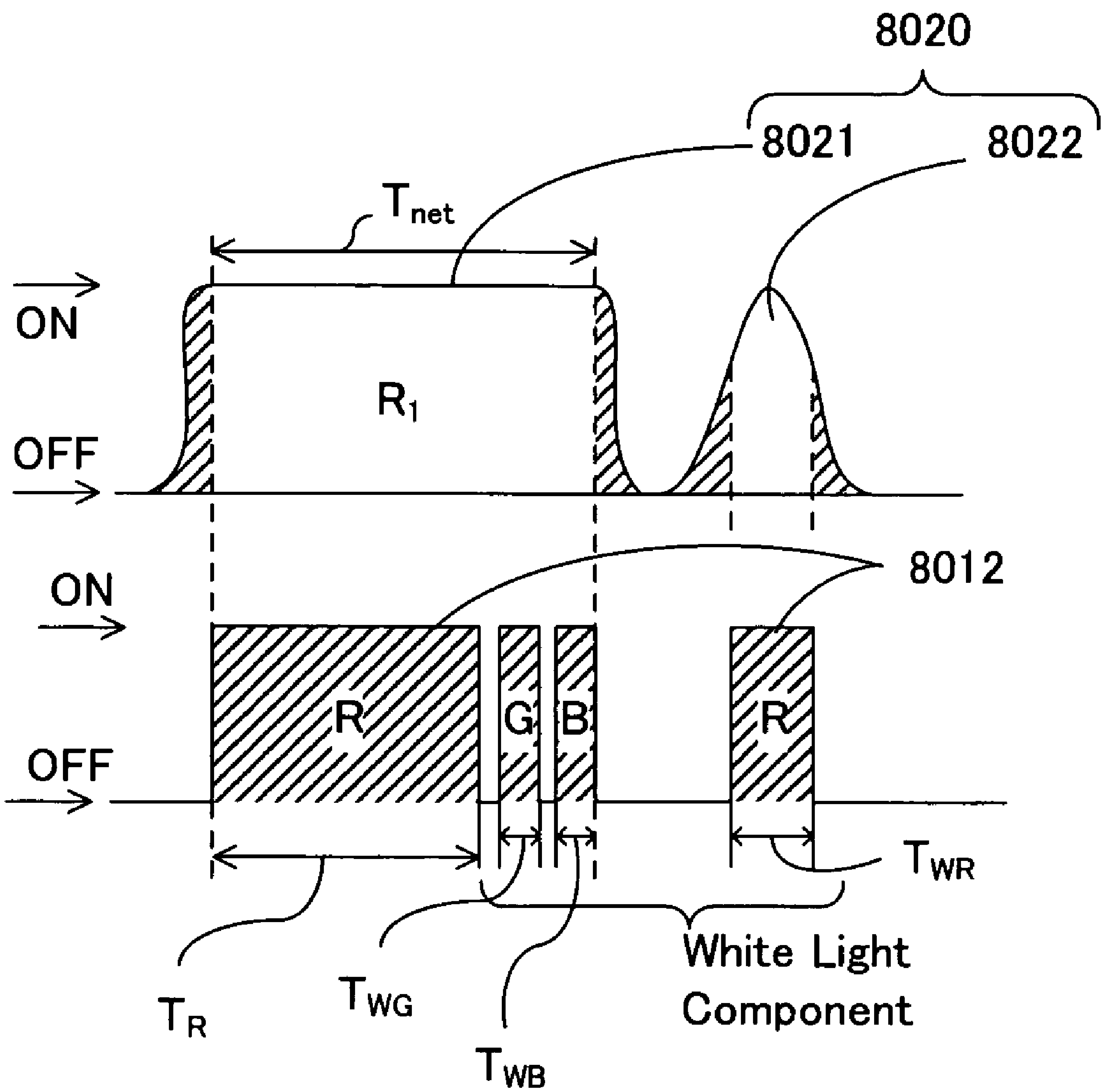

8020
8021
8022
Tnet
ON
R1
OFF
8012
ON
R
G
B
R
OFF
TWR
TR
TWG
TWB
White Light Component

FIG. 16

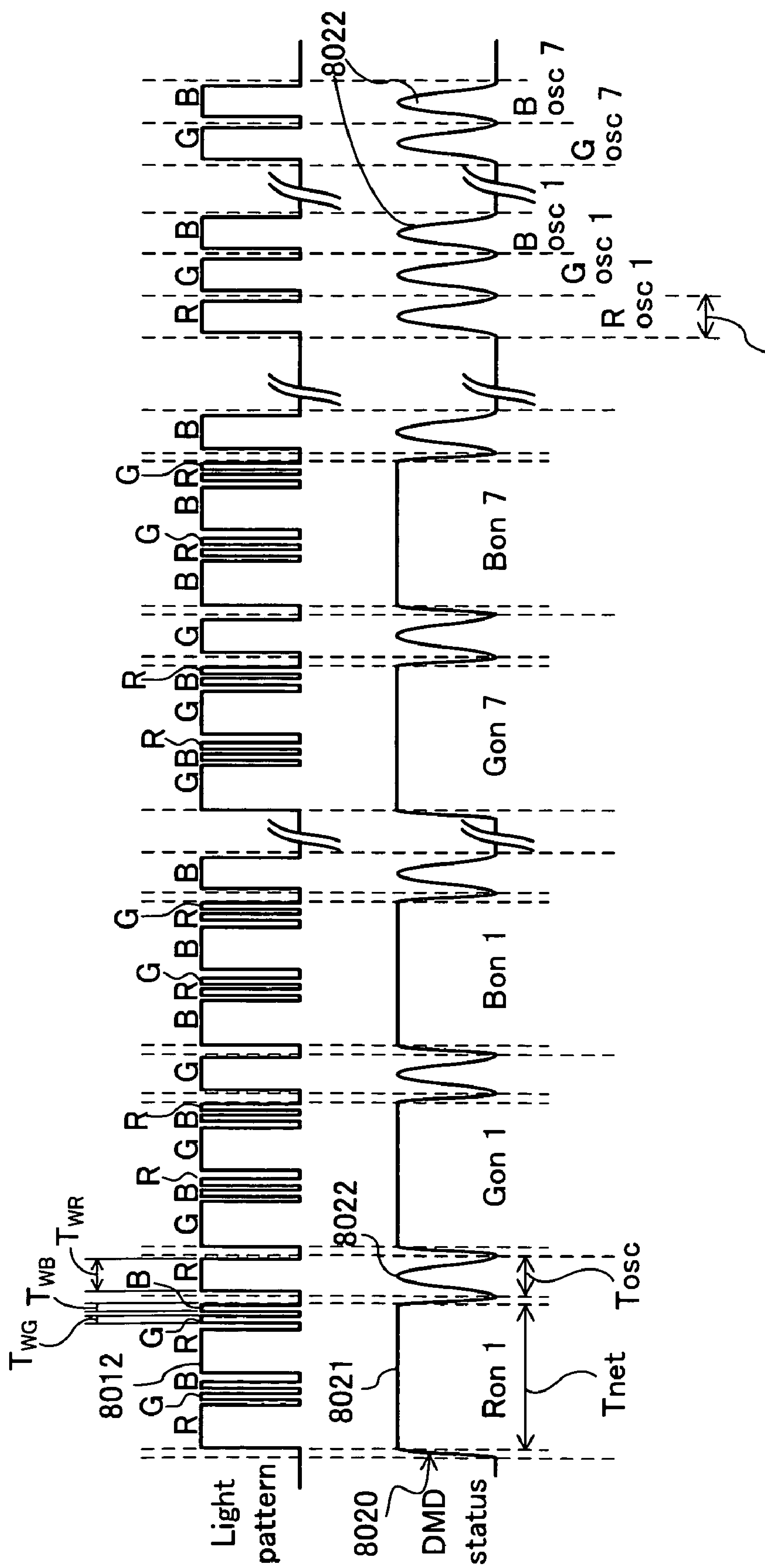

Light pattern
DMD status
8020
8021
8022
8012
T_{WG}
T_{WB}
T_{WR}
Ron 1
Gon 1
Bon 1
Gon 7
Bon 7
Tnet
Tosc
R osc 1
G osc 1
B osc 1
G osc 7
B osc 7
R
G
B

FIG. 17

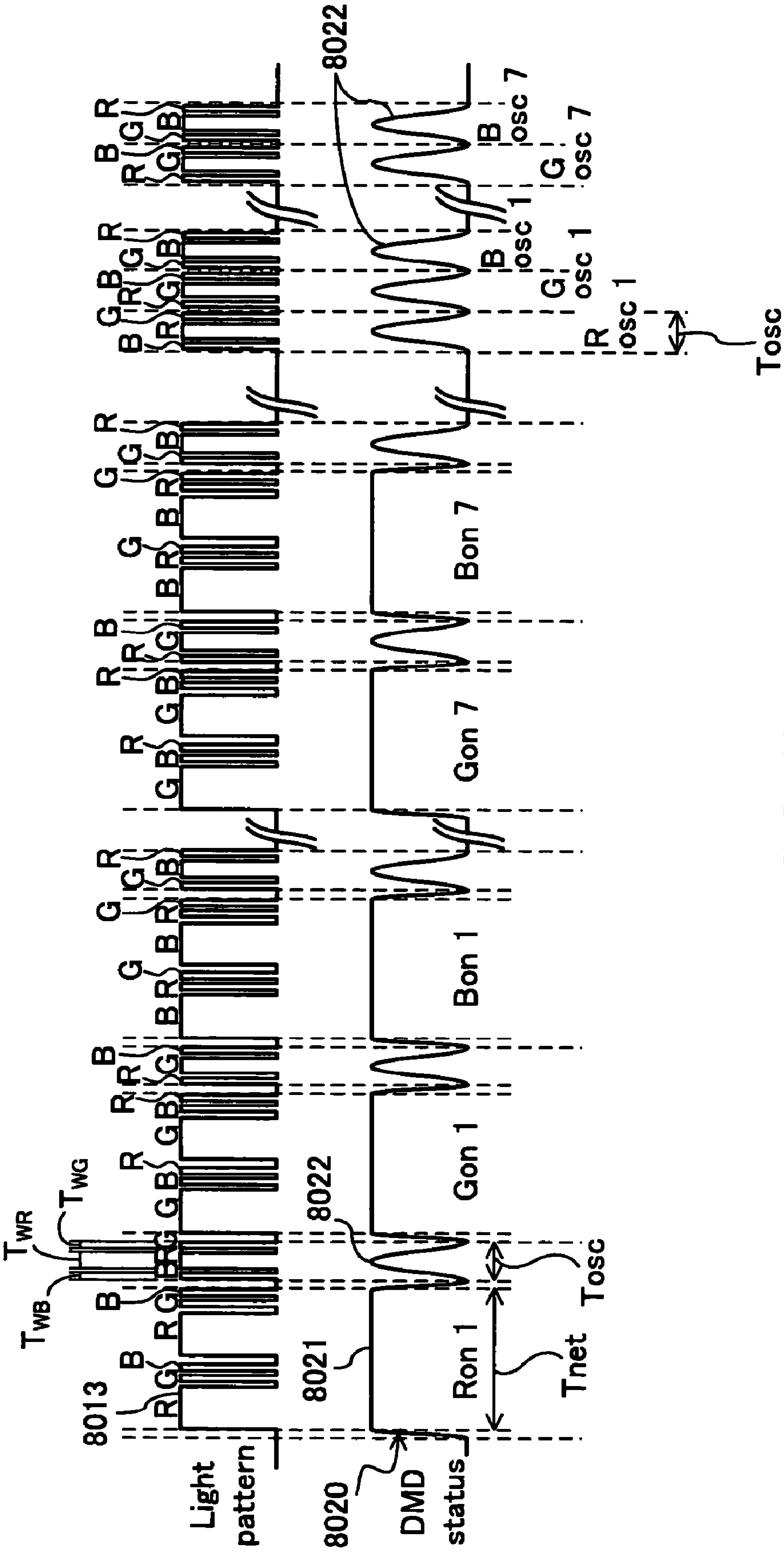

Light pattern
DMD status
8013
8020
8021
8022
T_{WB}
T_{WR}
T_{WG}
Ron 1
Gon 1
Bon 1
Gon 7
Bon 7
Tnet
Tosc
R osc 1
G osc 1
B osc 1
G osc 7
B osc 7

FIG. 18

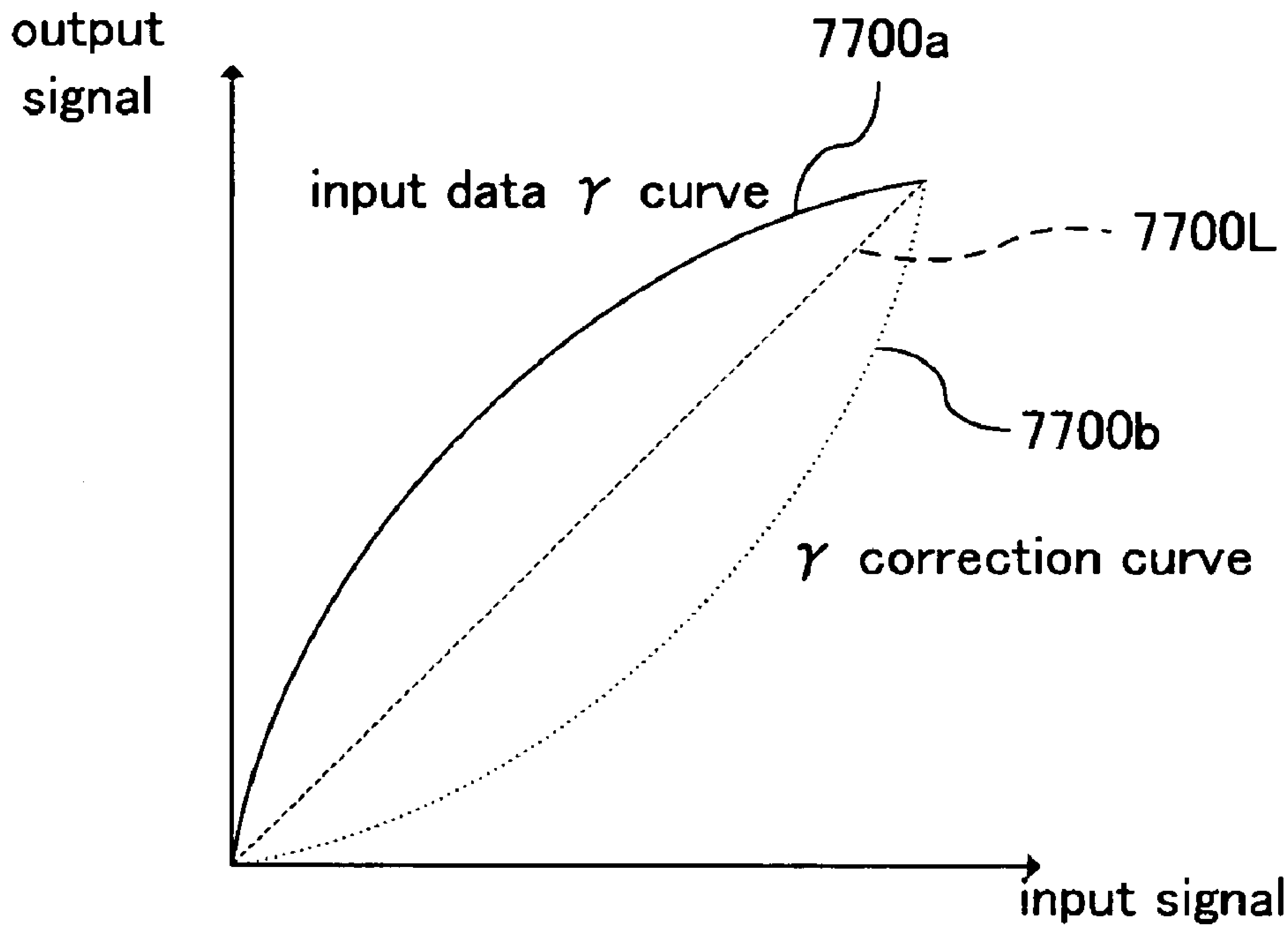

output signal
7700a
input data γ curve
7700L
7700b
γ correction curve
input signal

FIG. 19

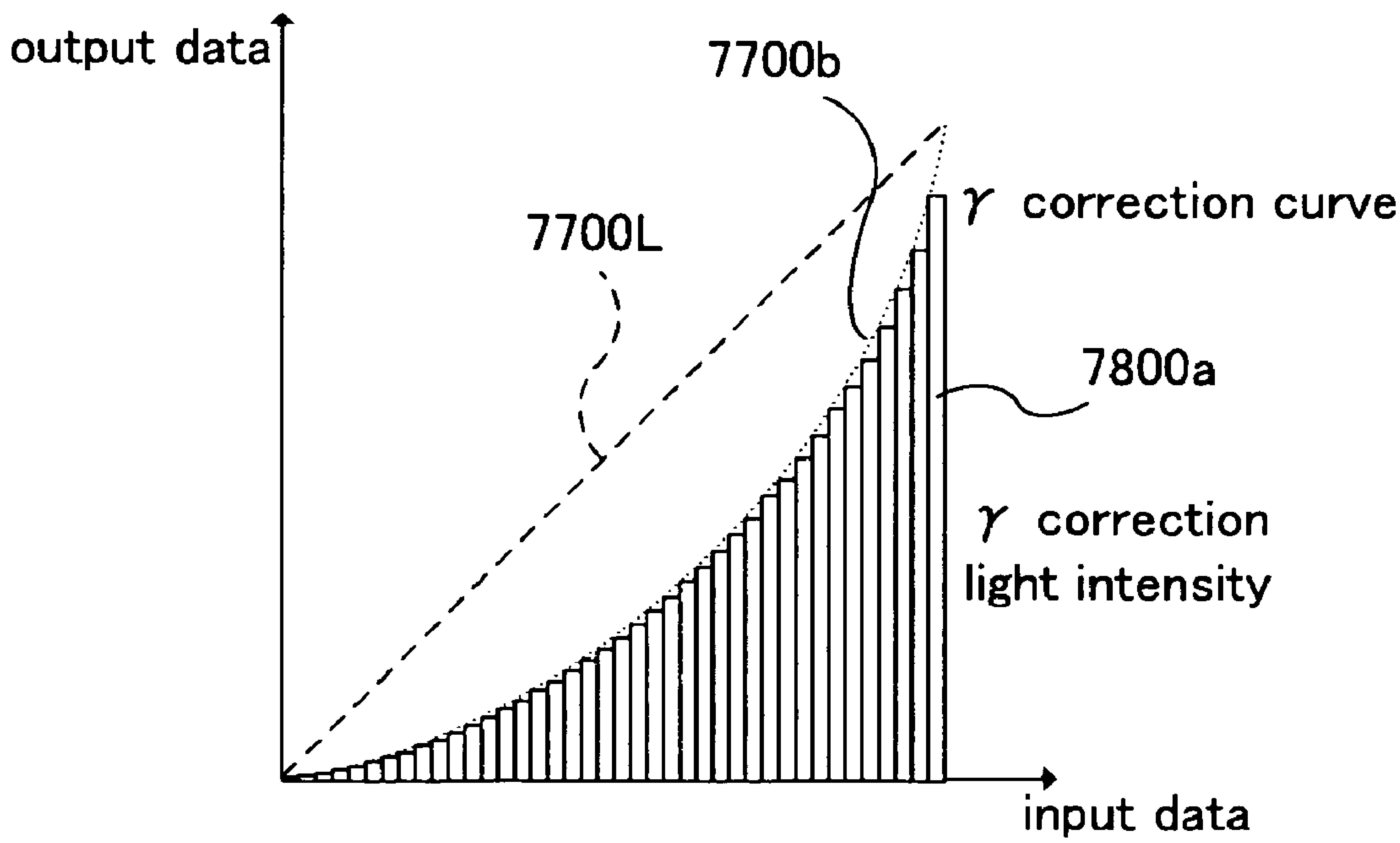
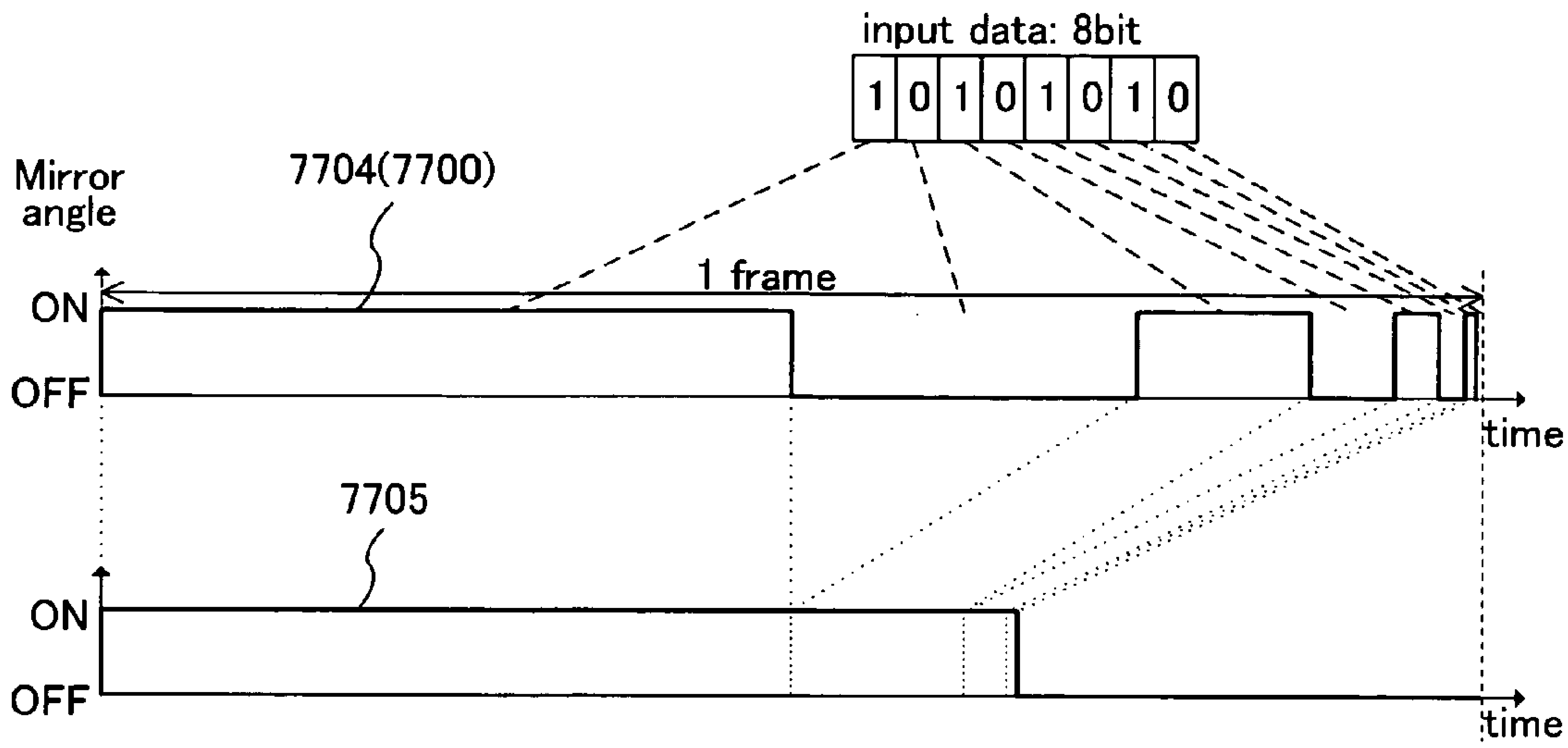
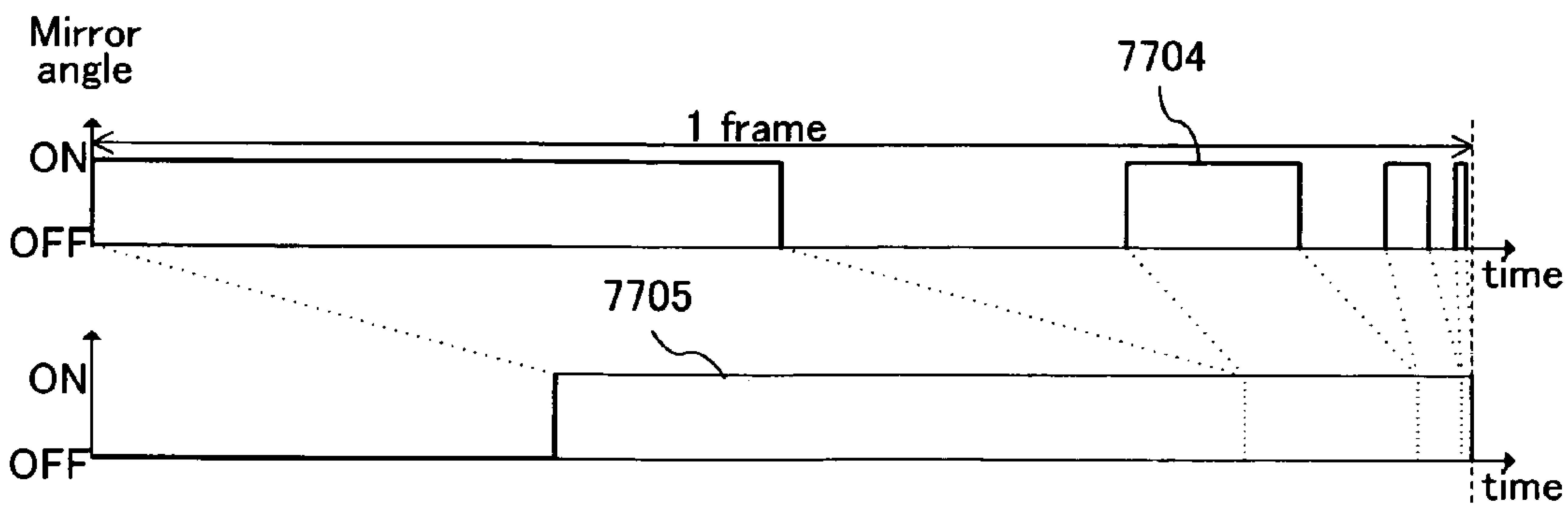

output data
7700b
γ correction curve
7700L
7800a
γ correction light intensity
input data

FIG. 20



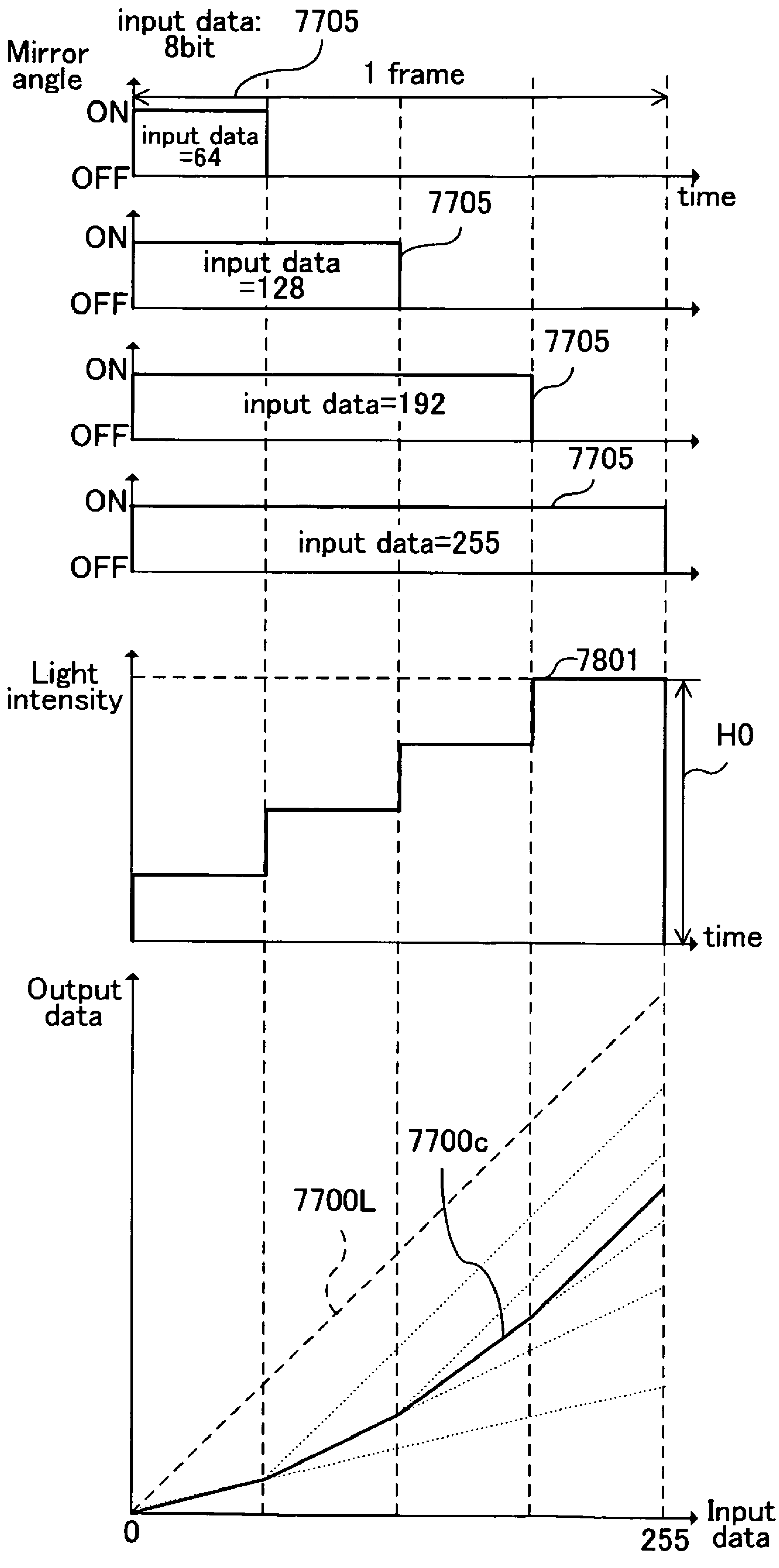
input data: 8bit
1 0 1 0 1 0 1 0
Mirror angle
7704(7700)
1 frame
ON
OFF
time
7705
ON
OFF
time

FIG. 21



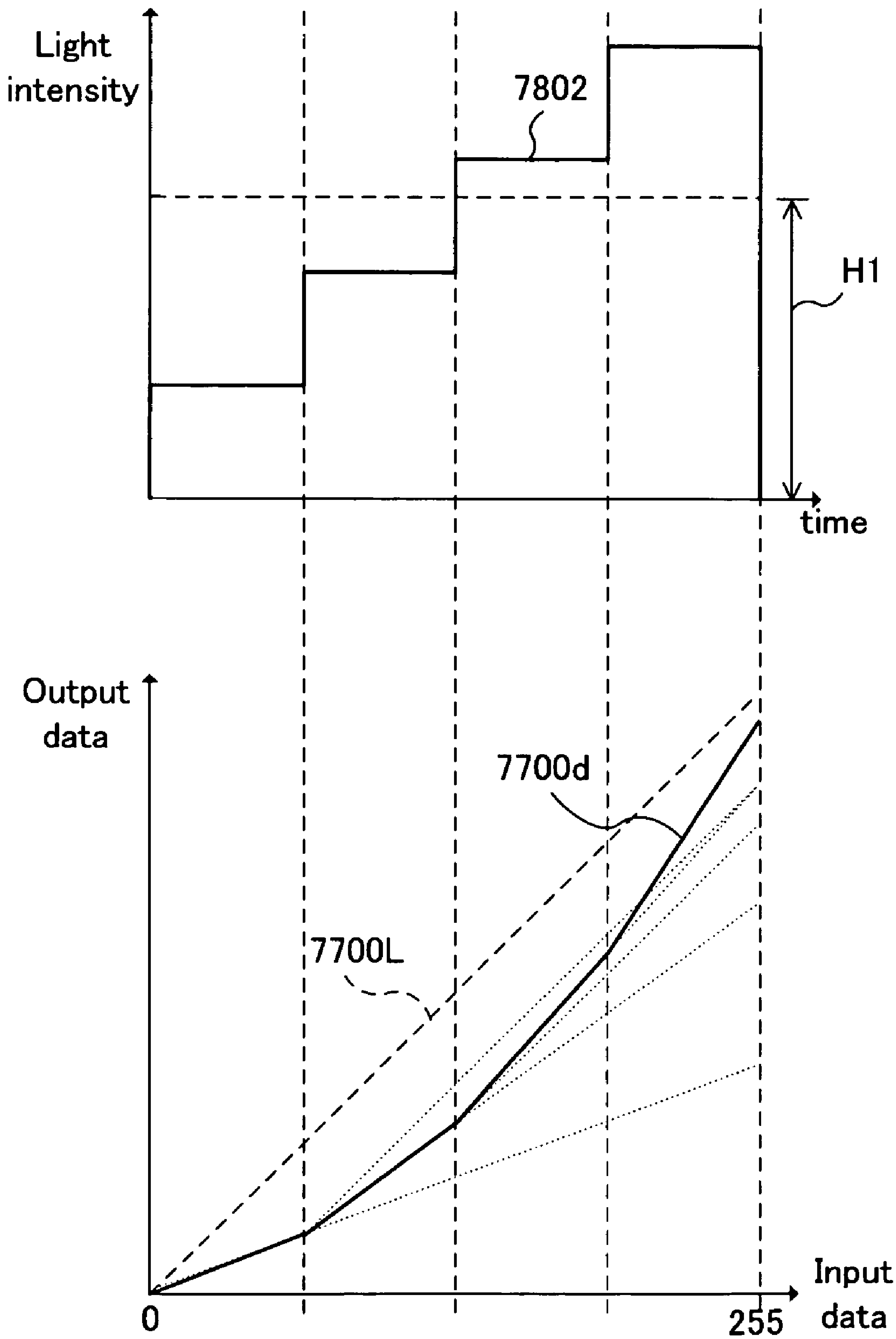
Mirror angle
7704
1 frame
ON
OFF
time
7705
ON
OFF
time

FIG. 22



input data: 8bit
7705
Mirror angle
1 frame
ON
OFF
input data =64
time
7705
input data =128
7705
input data=192
7705
input data=255
Light intensity
7801
H0
time
Output data
7700c
7700L
0
255
Input data

FIG. 23



Light
intensity
7802
H1
time
Output
data
7700d
7700L
0
255
Input
data

FIG. 24

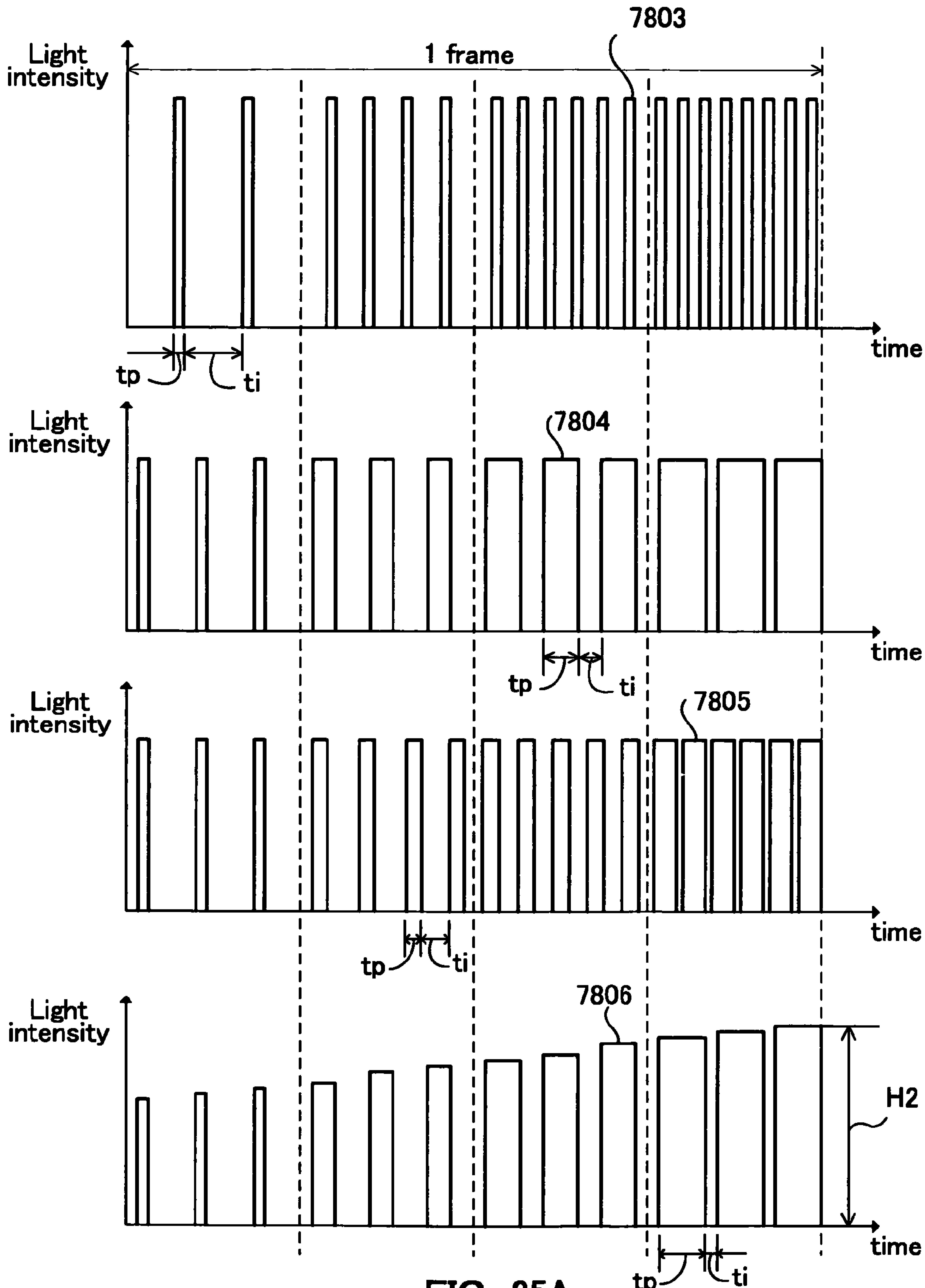
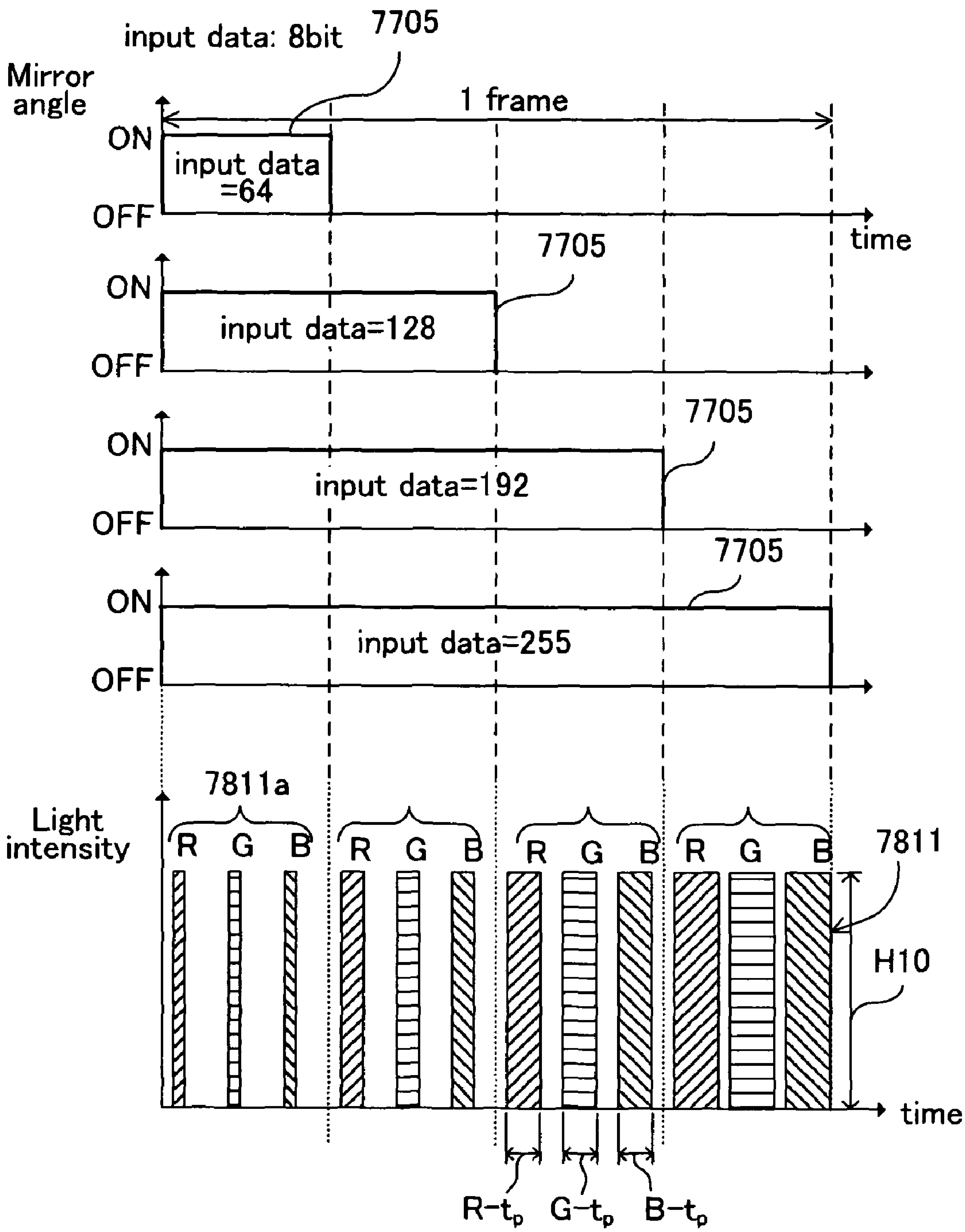
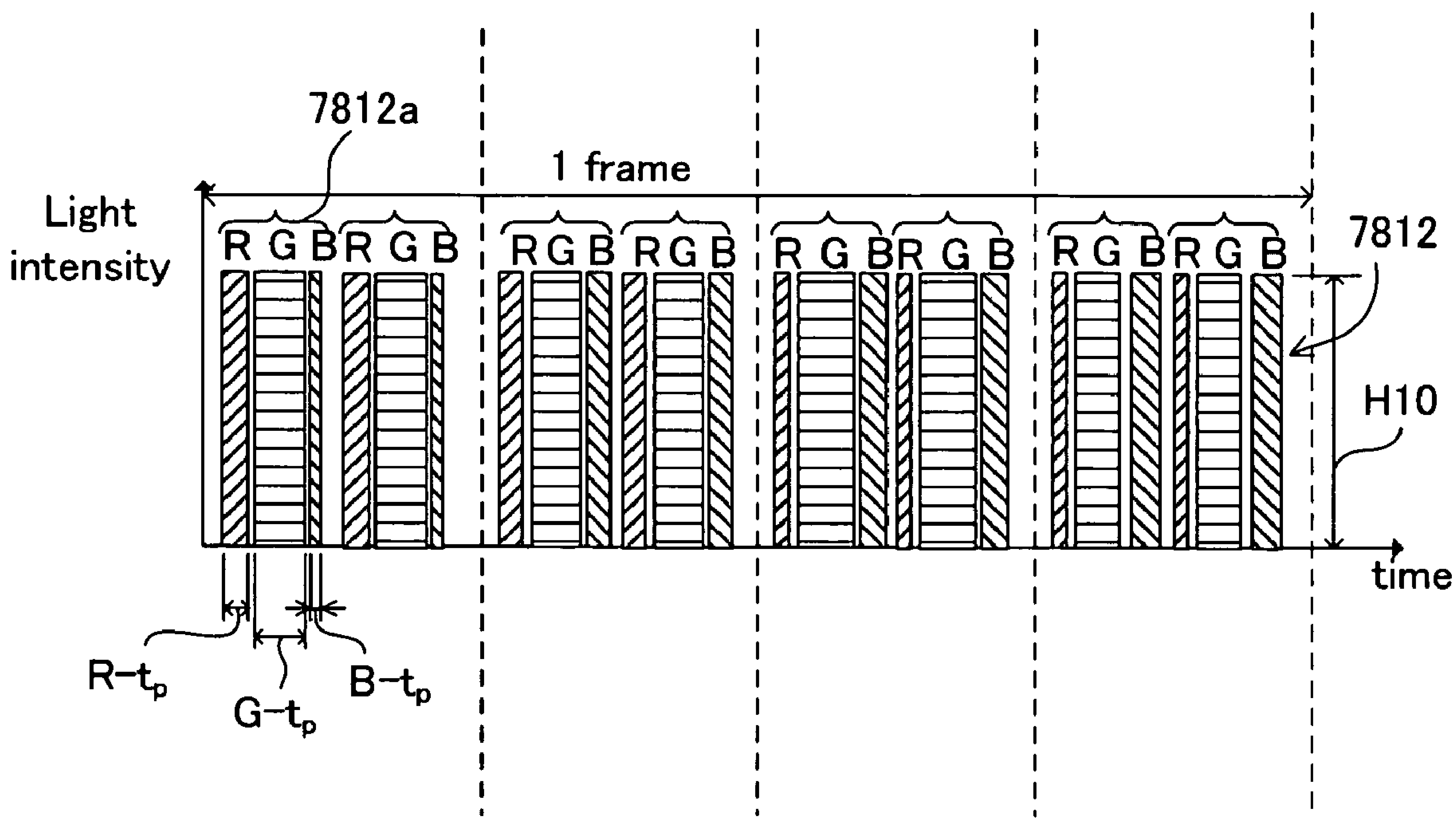

7803
Light intensity
1 frame
time
tp
ti
Light intensity
7804
time
tp
ti
Light intensity
7805
time
tp
ti
Light intensity
7806
H2
time
tp
ti

FIG. 25A



input data: 8bit
7705
Mirror angle
1 frame
ON
OFF
input data =64
time
7705
ON
OFF
input data=128
7705
ON
OFF
input data=192
7705
ON
OFF
input data=255
7811a
Light intensity
R G B
R G B
R G B
R G B
7811
H10
time
R-t_p
G-t_p
B-t_p

FIG. 25B



7812a
1 frame
Light intensity
R G B R G B R G B R G B R G B R G B R G B R G B
7812
H10
time
R-t_p
G-t_p
B-t_p

FIG. 25C

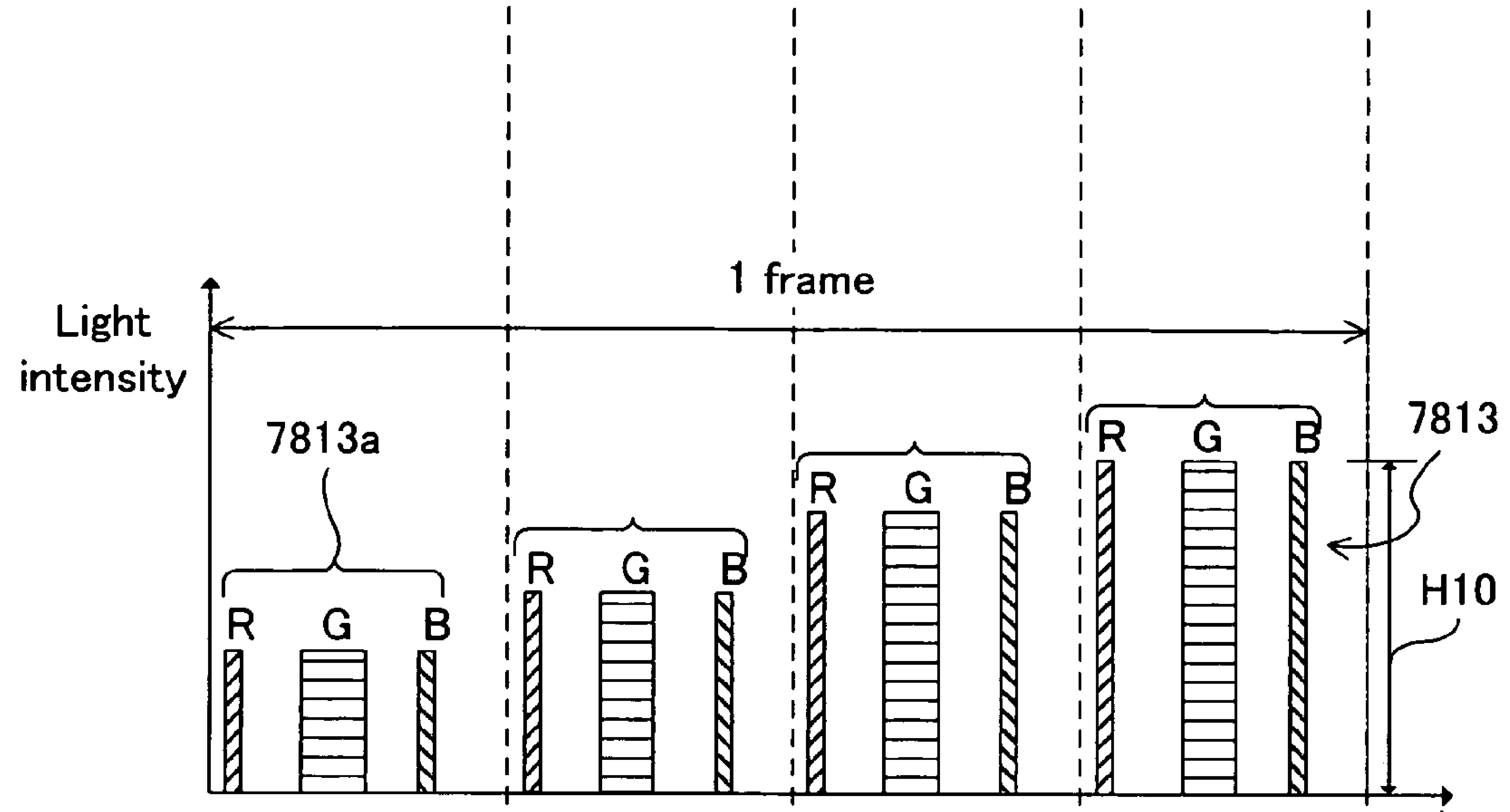


FIG. 25D

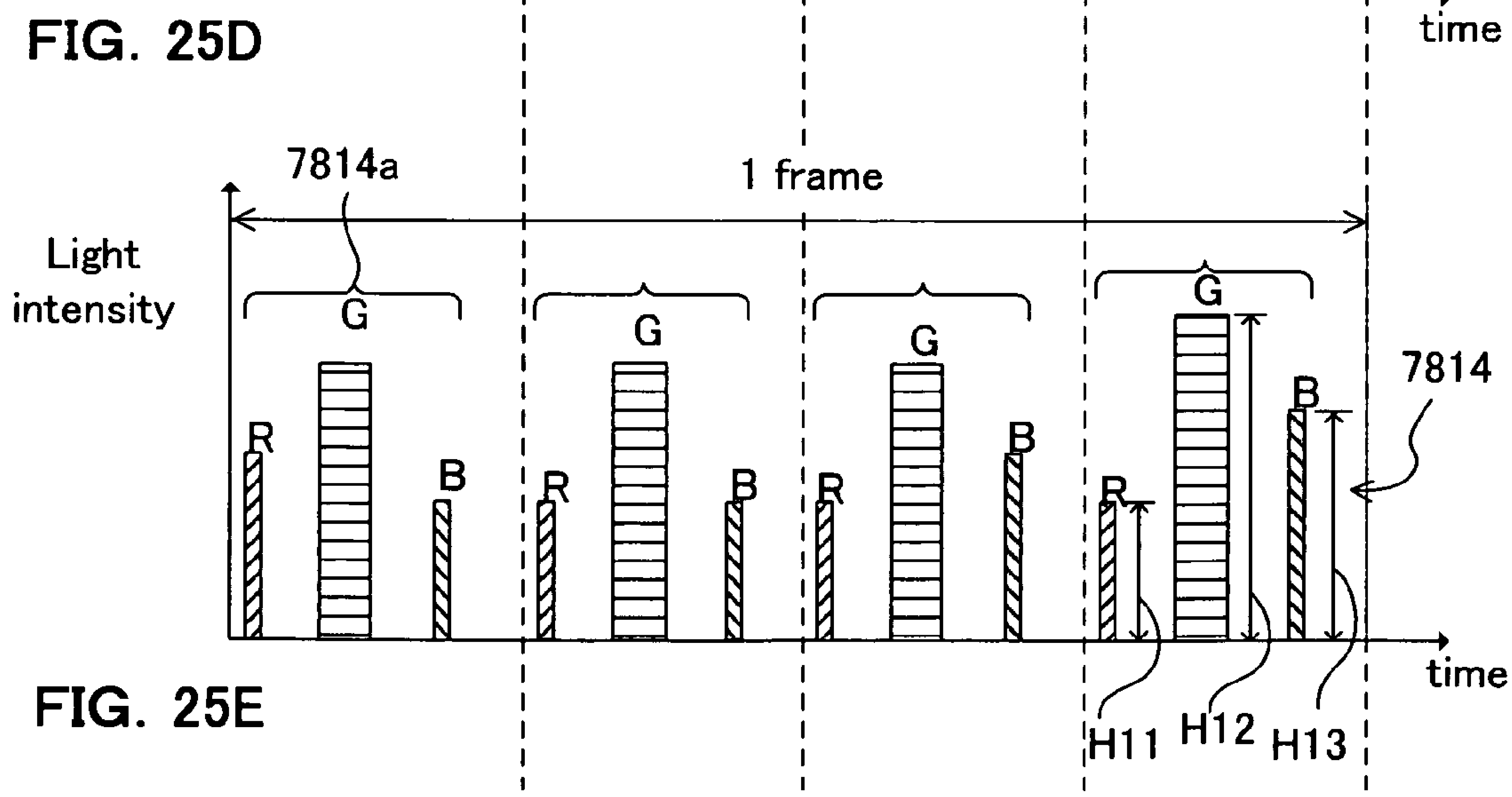


FIG. 25E

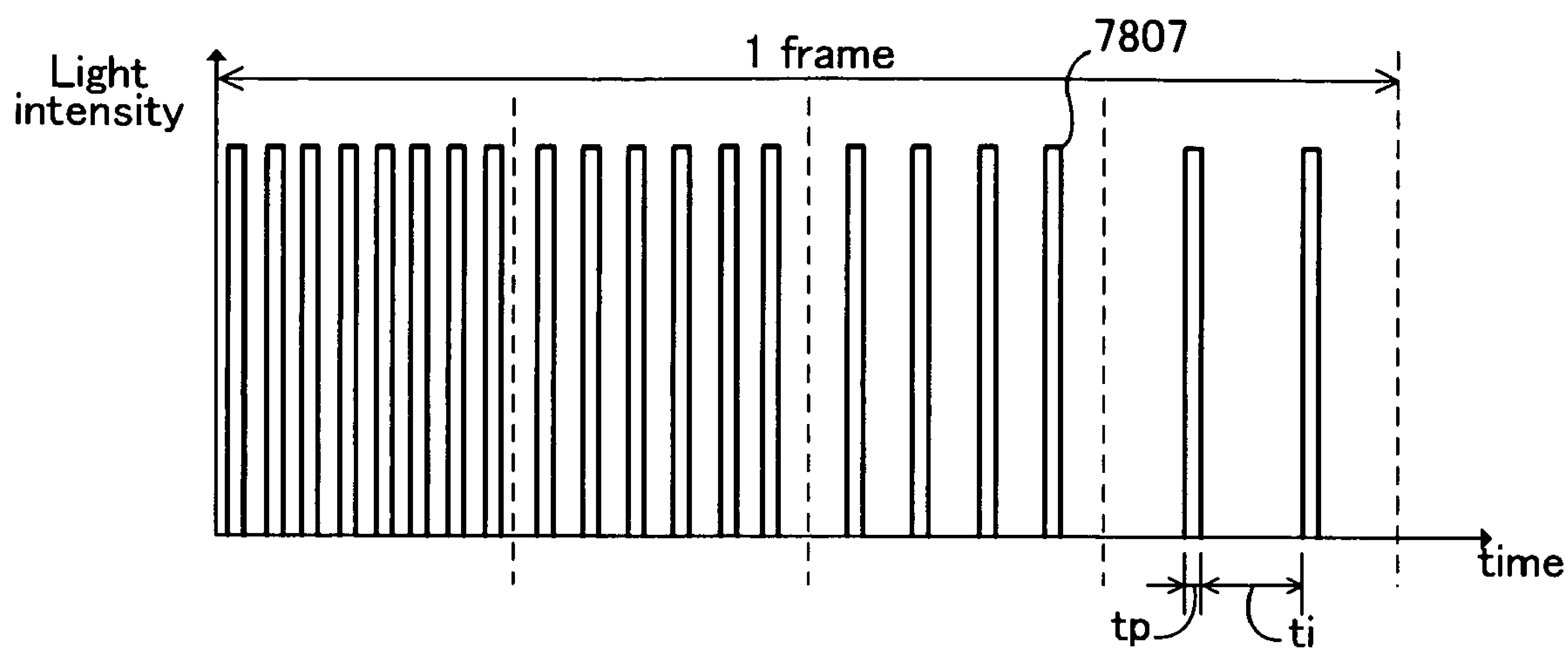


FIG. 26A

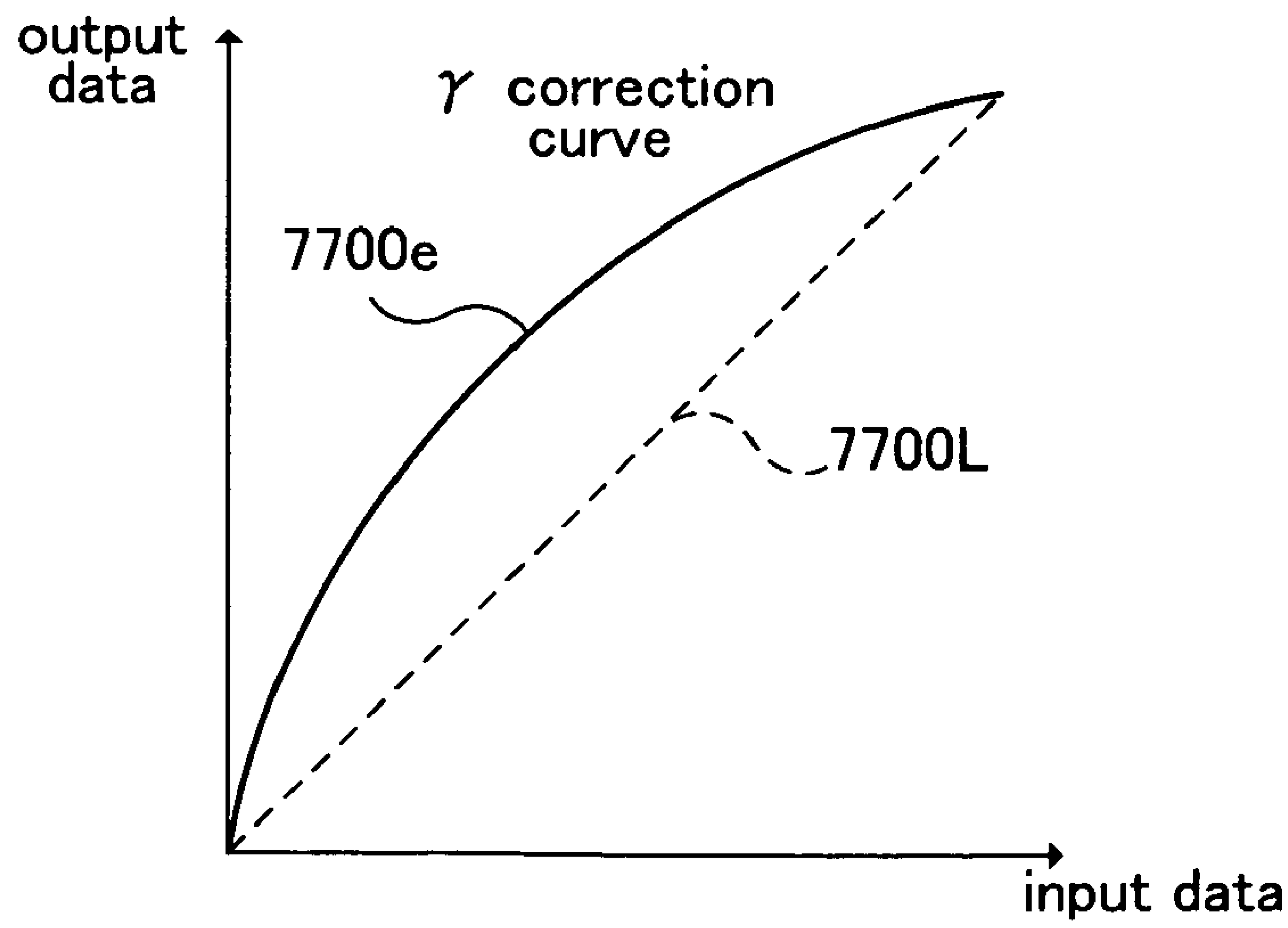


FIG. 26B

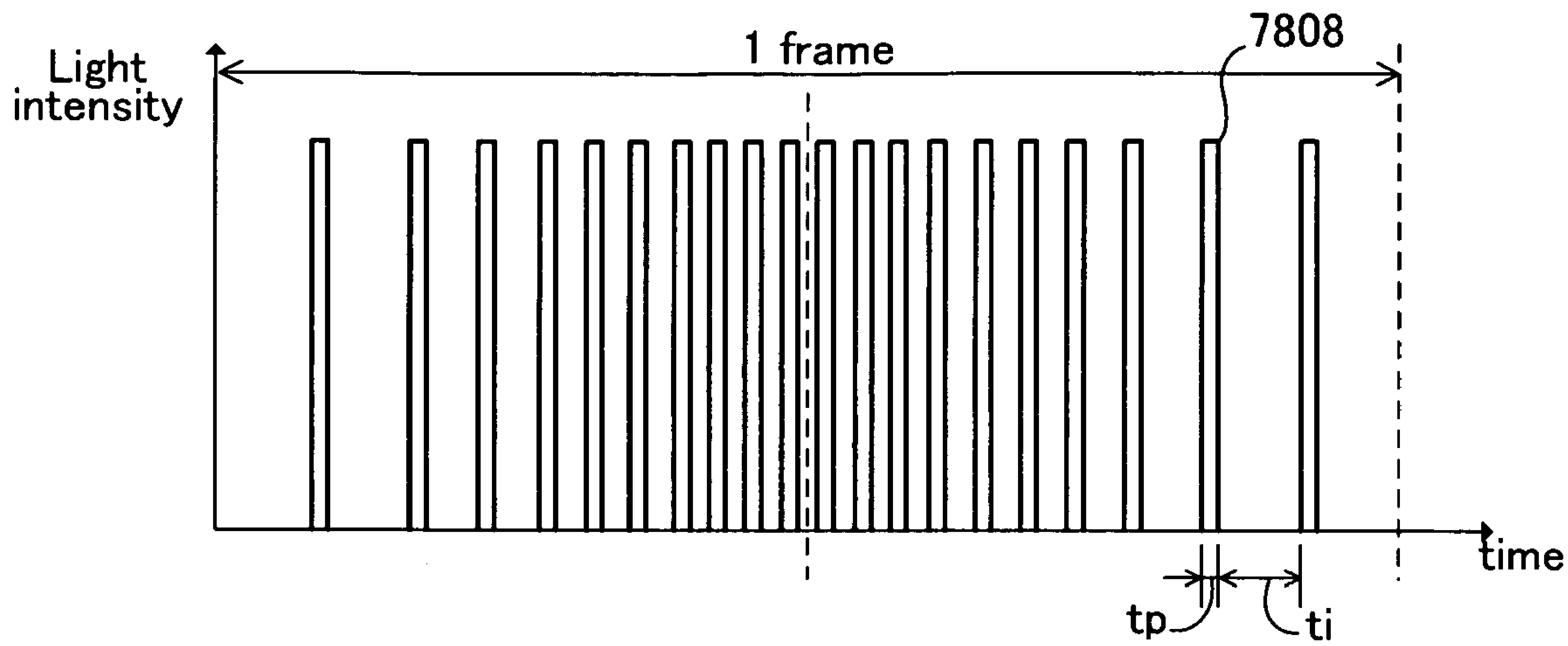


FIG. 27A

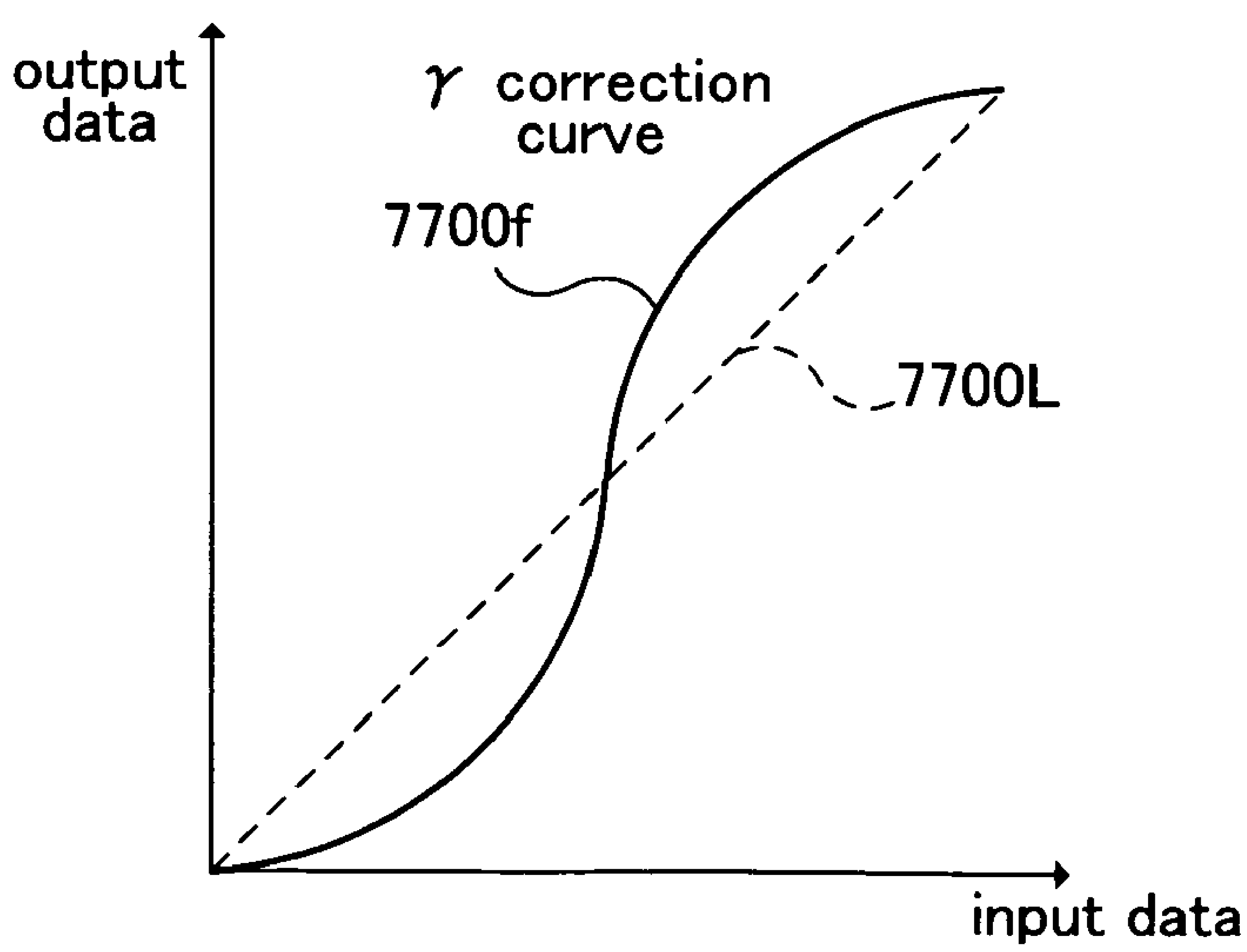


FIG. 27B

COLOR SEQUENTIAL ILLUMINATION FOR SPATIAL LIGHT MODULATOR

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a Non-provisional Application claiming a Priority date of Oct. 2, 2007 based on a previously filed Provisional Application 60/997,476 and a Non-provisional patent application Ser. No. 11/121,543 filed on May 3, 2005 issued into U.S. Pat. No. 7,268,932. The application Ser. No. 11/121,543 is a Continuation In Part (CIP) Application of three previously filed Applications. These three applications are Ser. No. 10/698,620 filed on Nov. 1, 2003, Ser. No. 10/699,140 filed on Nov. 1, 2003 now issued into U.S. Pat. No. 6,862,127, and Ser. No. 10/699,143 filed on Nov. 1, 2003 now issued into U.S. Pat. No. 6,903,860 by the Applicant of this patent applications. The disclosures made in these patent applications are hereby incorporated by reference in this patent application.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to the system configuration and methods for controlling and operating a projection apparatus. More particularly, this invention related to an image projection apparatus implemented with a plurality of spatial light modulators and light sources with a controller to control the modulators in different modulations states in coordination with the light sources emitting pulsed emissions to achieve optimal quality of image display.

2. Description of the Related Art

After the dominance of CRT technology in the display industry for over 100 years, Flat Panel Display (hereafter FPD) and Projection Display became popular because of its smaller form-factor and larger size of the screen. Among several types of projection displays, projection displays using micro-display are gaining recognition by consumers because of higher picture quality as well as lower cost than FPDs. There are two types of micro-displays used for projection displays in the market: micro-LCD (Liquid Crystal Display) and micro-mirror technology. Because a micro-mirror device uses the randomly polarized light, it is brighter than a micro-LCD, which uses polarized light.

Even though there have been significant advances made in recent years on the technologies of implementing electromechanical micro-mirror devices as spatial light modulator, there are still limitations and difficulties when these are employed to display high quality images. Specifically, when the display images are digitally controlled, the image quality is adversely affected because the image is not displayed with a sufficient number of gray scales.

The on-and-off states of micro-mirror control schemes, as that implemented in the U.S. Pat. No. 5,214,420 and by most of the conventional display systems such as that disclosed in U.S. Pat. No. 5,285,407 impose a limitation on the quality of the display. Specifically, with conventional configurations of the control circuit, the gray scale of conventional systems (PWM between ON and OFF states) is limited by the LSB (least significant bit, or the least pulse width). Due to the On-Off states implemented in the conventional systems, there is no way to provide a shorter pulse width than the LSB. The least brightness, which determines the gray scale, is the light reflected during the least pulse width. A limited gray scale leads to lower image quality.

In a simple example, and assuming n bits of gray scales, the frame time is divided into 2^n-1 equal time slices. For a 16.7 milliseconds frame period and n-bit intensity values, the time slice is $16.7/(2^n-1)$ milliseconds

Having established these times for each pixel of each frame, pixel intensities are quantified, such that black is 0 time slices, the intensity level represented by the LSB is 1 time slice, and the maximum brightness is 2^n-1 time slices. Each pixel's intensity determines it's the length of time the pixel is turned on during a frame period. Thus, during a frame period, each pixel with a value of more than 0 is on for the number of time slices that correspond to its intensity. The viewer's eye integrates the pixel's brightness so that the image appears the same as if it were generated with analog levels of light.

For addressing deformable mirror devices, PWM receives the data formatted into "bit-planes". Each bit-plane corresponds to a bit weight of the intensity value. Thus, if each pixel's intensity is represented by an n-bit value, each frame of data has n bit-planes. Each bit-plane has a 0 or 1 value for each display element. In the example described above, each bit-plane is separately loaded during a frame, and the display elements are addressed according to their associated bit-plane values. For example, the bit-plane representing the LSBs of each pixel is displayed for 1 time slice.

Projection apparatuses, such as those described above, generally use a light source such as a high-pressure mercury lamp or a xenon lamp. However, these types of light sources perform poorly in high-speed switching that alternate between the ON and OFF states. Because of this, these lamps are commonly controlled to be in a continuous ON state while the apparatus is in operation. Thus, it is not possible to accurately control the light intensity in the transition state, between an ON state and an OFF state, for an ON/OFF modulation of a mirror. This causes a degradation of image quality in the modulation control of a video image when using a spatial light modulator.

Furthermore, when the intensity of light modulated by a spatial light modulator is only controlled by the ON/OFF operation of the mirror, the oscillation speed of the mirror needs to be increased in order to implement a finer control of the light intensity. Increasing the oscillation speed of the mirror, however, is limited by a number of factors including the strength of a hinge constituting the mirror and the frequency of the control signal used for the tilt (i.e., oscillation) control, such as the ON/OFF control. Thus, there will be a limitation in controlling light intensity when only the ON/OFF controls of the mirror are used to control the modulation of light intensities.

In order to control the color temperature and/or color balance, the input video signal needs to be processed. Because of this, further technical problems, such as an unnecessarily complex process circuit for the video, are introduced.

SUMMARY OF THE INVENTION

A purpose of the present invention is to provide a system configuration and control process to more accurately control the intensity of the modulated light without being influenced by the transition state between the ON and OFF states of the ON/OFF modulation of a mirror.

Another purpose of the present invention is to provide a system configuration and control process to more accurately control the intensity of the modulated light independent of the speed of the tilt control of a mirror.

Yet another purpose of the present invention is to provide a system configuration and control process to more accurately control a color temperature and a color balance without requiring an input video signal to be changed.

A first exemplary embodiment of the present invention provides a display apparatus, comprising: a light source or light sources for emitting a luminous flux or luminous fluxes having a plurality of colors; a spatial light modulator for modulating the luminous flux(es) having a plurality of colors incoming from the light sources; and controller for processing video image input data, and controlling the light source(s) and the spatial light modulator, wherein the controller generates a plurality of video image signals of colors constituting a video image on the basis of the video image input data, and controls the light source(s) to project at least two colors, from among the light source(s) having a plurality of colors, to perform pulse emission in sequence and modulate the pulse emission during a period shorter than a period of a modulation state controlled under the spatial light modulator by applying the video image signal of one color from among the video image signals.

A second exemplary embodiment of the present invention provides the display apparatus according to the first exemplary embodiment, wherein a period of a modulation state controlled under the spatial light modulator is a minimum unit time for controlling the spatial light modulator under a modulation state on the basis of the video image information.

A third exemplary embodiment of the present invention provides the display apparatus according to the first exemplary embodiment, wherein the minimum unit time is a period of time in accordance with a period of time in accordance with a period of time for loading, onto the pixel of the spatial light modulator, a minimum unit of data to control the gradation of the brightness of the spatial light modulator on the basis of the video image information.

A fourth exemplary embodiment of the present invention provides the display apparatus according to the first exemplary embodiment, wherein the light source is a light emitting diode (LED) or laser light source.

A fifth exemplary embodiment of the present invention provides the display apparatus according to the first exemplary embodiment, wherein the spatial light modulator is controlled under a plurality of modulation states in accordance with a control signal from the controller.

A sixth exemplary embodiment of the present invention provides the display apparatus according to the first exemplary embodiment, further comprising projector, wherein the spatial light modulator is a mirror device comprising a plurality of micromirrors, and the projector projects the modulation light of the spatial light modulator.

A seventh exemplary embodiment of the present invention provides the display apparatus according to the sixth exemplary embodiment, wherein the spatial light modulator is controlled under any of an ON state for guiding the luminous flux emitted from the light source to the projector, of an OFF state for guiding the luminous flux emitted from the light source away from the projector and of an oscillation state that is between the ON state and OFF state, with a control signal from the controller.

An eighth exemplary embodiment of the present invention provides the display apparatus according to the first exemplary embodiment, wherein the controller converts an inputted binary video signal into a non-binary video signal, and the modulation of the spatial light modulator is controlled on the basis of the non-binary signal.

A ninth exemplary embodiment of the present invention provides the display apparatus according to the first exemplary embodiment, wherein the modulation of the pulse emission is the modulation of a pulse width.

A tenth exemplary embodiment of the present invention provides the display apparatus according to the first exemplary embodiment, wherein the modulation of the pulse emission is the modulation of a pulse intensity.

An eleventh exemplary embodiment of the present invention provides the display apparatus according to the first exemplary embodiment, wherein the controller adjusts the color balance of a video image to be displayed by controlling the modulation of the pulse emission.

A twelfth exemplary embodiment of the present invention provides the display apparatus according to the eleventh exemplary embodiment, further comprising video image analysis means for analyzing the brightness of each color of an inputted video image signal, wherein the controller adjusts the color balance by controlling the modulation of the pulse emission in accordance with a control signal from the video image analysis means.

A thirteenth exemplary embodiment of the present invention provides the display apparatus according to the eleventh exemplary embodiment, wherein the modulation of the pulse emission is different between a time when the brightness data of each pixel is that of a dark pixel and a time when the bright brightness of each pixel is that of a bright pixel.

A fourteenth exemplary embodiment of the present invention provides the display apparatus according to the eleventh exemplary embodiment, further comprising a mirror device comprising a plurality of micromirrors as spatial light modulator, wherein the sets of sequential emission of respective colors are repeated for a plurality of times to change at least either of the pulse widths and pulse intensities of the pulse emission of the respective colors in each of the aforementioned sets within the display period of one frame in which the durations of the ON state of the micromirror are changed in accordance with the brightness data.

A fifteenth exemplary embodiment of the present invention provides the display apparatus according to the fourteenth exemplary embodiment, wherein the ratio of light intensities of individual colors within each set of the sequential emission is controlled to be constant.

A sixteenth exemplary embodiment of the present invention provides the display apparatus according to the fourteenth exemplary embodiment, wherein the ratio of light intensities of individual colors within each set of the sequential emission is controlled to be variable.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a functional block diagram showing the configuration of a projection apparatus according to a preferred embodiment of the present invention;

FIG. **2** is a functional block diagram showing the configuration of a single-panel looks like a multi-panel to me projection apparatus according to another preferred embodiment of the present invention;

FIG. **3**A is a functional block diagram exemplifying the configuration of a control unit comprised in a single-panel projection apparatus according to a preferred embodiment of the present invention;

FIG. **3**B is a functional block diagram exemplifying the configuration of a control unit comprised in a multi-panel projection apparatus according to a preferred embodiment of the present invention;

FIG. **4**A is a block diagram for showing the configuration of a light source drive circuit of a projection apparatus according to a preferred embodiment of the present invention;

FIG. 4B is a block diagram showing an exemplary modification of the configuration of a light source drive circuit of a projection apparatus according to a preferred embodiment of the present invention;

FIG. 5 is a chart showing the relationship between the emission light intensity and the applied current of the light source drive circuit of the embodiment of the present invention;

FIG. 6 is a chart showing the relationship between the emission light intensity and the applied current of the constant current circuit of the light source drive circuit of the embodiment of the present invention;

FIG. 7 is a circuit diagram for showing the layout of the internal configuration of a spatial light modulator according to the embodiment of the present invention;

FIG. 8 is a cross-sectional diagram of an individual pixel part constituting a spatial light modulator according to the embodiment of the present invention;

FIG. 9 is a side cross sectional view for showing the configuration of an individual pixel unit constituting a spatial light modulator according to the embodiment of the present invention;

FIG. 10A is a diagram depicting the state in which an incident light is reflected towards a projection optical system by deflecting the mirror of a mirror element according to a preferred embodiment of the present invention;

FIG. 10B is a diagram depicting the state in which an incident light is reflected away from a projection optical system by deflecting the mirror of a mirror element according to the embodiment of the present invention;

FIG. 10C is a diagram depicting the state in which incident light is reflected towards and away from a projection optical system by the repeated free-oscillation of the mirror of a mirror element according to the embodiment of the present invention;

FIG. 11 is a chart exemplifying the operation of a projection apparatus according to a preferred embodiment of the present invention;

FIG. 12 is a chart exemplifying the operation of a projection apparatus according to a preferred embodiment of the present invention;

FIG. 13 is a chart exemplifying the operation of a projection apparatus according to a preferred embodiment of the present invention;

FIG. 14 is a chart showing the principle of controlling a color balance in a projection apparatus according to a preferred embodiment of the present invention;

FIG. 15 is a chart showing the principle of controlling a color balance in the ON/OFF control of a mirror in a projection apparatus according to a preferred embodiment of the present invention;

FIG. 16 is a chart showing the principle of controlling a color balance in the case of combining the ON/OFF control of a mirror with the oscillation control thereof in a projection apparatus according to a preferred embodiment of the present invention;

FIG. 17 is a chart exemplifying the operation in the case of combining the ON/OFF control of a mirror with the oscillation control thereof in a projection apparatus according to a preferred embodiment of the present invention;

FIG. 18 is a chart exemplifying the operation in the case of combining the ON/OFF control of a mirror with the oscillation control thereof in a projection apparatus according to a preferred embodiment of the present invention;

FIG. 19 is a chart describing the principle of a gamma (γ) correction for video image data;

FIG. 20 is a chart showing the principle of a gamma correction by controlling the emission light intensity of a light source carried out in a projection apparatus according to the embodiment of the present invention;

FIG. 21 is a chart describing an example of converting binary data into non-binary data carried out in a projection apparatus according to the embodiment of the present invention;

FIG. 22 is a chart describing an example of converting binary data into non-binary data carried out in a projection apparatus according to the embodiment of the present invention;

FIG. 23 is a chart showing an example of carrying out a gamma correction in the brightness input of 8-bit non-binary data in four stages in a projection apparatus according to the embodiment of the present invention;

FIG. 24 is a chart showing an exemplary modification of carrying out a gamma correction in the brightness input of 8-bit non-binary data in four stages in a projection apparatus according to the embodiment of the present invention;

FIG. 25A is a chart exemplifying a gamma correction by means of intermittent pulse emission in a projection apparatus according to the embodiment of the present invention;

FIG. 25B is a chart describing an exemplary modification of the modulation of pulse emission of a adjustable light source comprised in a projection apparatus according to the embodiment of the present invention;

FIG. 25C is a chart describing an exemplary modification of the modulation of pulse emission of a adjustable light source comprised in a projection apparatus according to the embodiment of the present invention;

FIG. 25D is a chart describing an exemplary modification of the modulation of pulse emission of a adjustable light source comprised in a projection apparatus according to the embodiment of the present invention;

FIG. 25E is a chart describing an exemplary modification of the modulation of pulse emission of a adjustable light source comprised in a projection apparatus according to the embodiment of the present invention;

FIG. 26A is a chart exemplifying a gamma correction for increasing a correction effect on a lower brightness side by means of intermittent pulse emission in a projection apparatus according to the embodiment of the present invention;

FIG. 26B is a chart exemplifying a gamma correction curve for performing a gamma correction for increasing a correction effect on a lower brightness side by means of a light source pattern shown in FIG. 26A;

FIG. 27A is a chart exemplifying a gamma correction with consideration for human vision by means of intermittent pulse emission in a projection apparatus according to the embodiment of the present invention; and

FIG. 27B is a chart exemplifying a gamma correction curve for performing a gamma correction with consideration for human vision by means of the light source pulse pattern shown in FIG. 27A.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following is a detailed description of the preferred embodiments of the present invention with reference to the accompanying drawings. More specifically, the following description is provided for the application of the present invention to a projection apparatus as an example of display apparatuses.

FIG. 1 is a functional block diagram for showing the configuration of a single panel projection apparatus according to a preferred embodiment of the present invention. Specifically, FIG. **1** shows a projection apparatus **5010** that includes a single spatial light modulator (SLM) **5100**, a control unit **5500**, a Total Internal Reflection (TIR) prism **5300**, a projection optical system **5400** and a light source optical system **5200**. The projection apparatus **5010** is commonly referred to as a single-panel projection apparatus **5010** because the apparatus is implemented with a single spatial light modulator **5100**.

The projection optical system **5400** is implemented with a spatial light modulator **5100** and TIR prism **5300** disposed on the optical axis of the projection optical system **5400**, and the light source optical system **5200** is placed with a configuration to have an optical axis matches the optical axis of the projection optical system **5400**.

The TIR prism **5300** receives the incoming illumination light **5600** projected from the light source optical system **5200** and directs the light to transmit as incident light **5601** to the spatial light modulator **5100** at a prescribed inclination angle. The SLM **5100** further reflects and transmits a reflection light **5602** towards the projection optical system **5400**.

The projection optical system **5400** projects the reflection light **5602** from the SLM **5100** and TIR prism **5300** onto a screen **5900** as projection light **5603**. The light source optical system **5200** comprises a adjustable light source **5210** for generating the illumination light **5600**, a condenser lens **5220** for focusing the illumination light **5600**, a rod type condenser body **5230** and a condenser lens **5240**.

The adjustable light source **5210**, condenser lens **5220**, rod type condenser body **5230** and condenser lens **5240** are sequentially placed in the aforementioned order in the optical axis of the illumination light **5600** emitted from the adjustable light source **5210** and incident to the side face of the TIR prism **5300**.

The projection apparatus **5010** employs a single spatial light modulator **5100** for implementing a color display on the screen **5900** by means of a sequential color display method.

Specifically, the adjustable light source **5210**, comprising a red **5211**, a green **5212**, and a blue laser light source **5213** (not shown in the drawing), allows independent control of the light emission states. The controller of the adjustable light source divides one frame of display data into a plurality of sub-fields (i.e., three sub-fields, specifically, red (R), green (G) and blue (B) in the present case) and makes each of the laser light sources, the red **5211**, green **5212** and blue **5213**, emit each respective light in time series at the time band corresponding to the sub-field of each color, as will be described later.

FIG. **2** is a functional block diagram showing the configuration of a projection apparatus according to another preferred embodiment of the present invention.

The projection apparatus **5020** is commonly referred to as a multi-plate projection apparatus comprising a plurality of spatial light modulators **5100** instead of a single SLM included in the single-panel projection apparatus **5010** described above. Furthermore, the projection apparatus **5020** comprises a control unit **5502** in place of the control unit **5500**.

The projection apparatus **5020** comprises a plurality of spatial light modulators **5100**, and further includes a light separation/synthesis optical system **5310** between the projection optical system **5400** and each of the spatial light modulators **5100**.

The light separation/synthesis optical system **5310** comprises a plurality of TIR prisms, i.e., TIR prism **5311**, TIR prism **5312**, and TIR prism **5313**.

The TIR prism **5311** functions to direct the illumination light **5600**, projected along the optical axis of the projection optical system **5400**, to the spatial light modulator **5100** as incident light **5601**.

The TIR prism **5312** functions to separate the red (R) light from an incident light **5601**, projected by way of the TIR prism **5311**, transmitting the red light incident to the red light-use spatial light modulators **5100**, and further directs the reflection light **5602** of the red light to the TIR prism **5311**.

Likewise, the TIR prism **5313** functions to separate the blue (B) and green (G) lights from the incident light **5601**, projected by way of the TIR prism **5311**, and transmits them to the blue color-use spatial light modulator **5100** and green color-use spatial light modulator **5100**, and further functions to direct the reflection light **5602** of the green light and blue light to the TIR prism **5311**.

Therefore, the spatial light modulations of these three colors of R, G and B are simultaneously performed at three spatial light modulators **5100**, respectively. The reflection lights, resulting from the respective modulations, are projected onto the screen **5900** as the projection light **5603** by way of the projection optical system **5400**, and thus a color display is carried out.

Note that the system may implement various modifications by using a light separation/synthesis optical system instead of being limited to the light separation/synthesis optical system **5310** described above.

FIG. **3**A is a functional block diagram exemplifying the configuration of a control unit comprised in a single-panel projection apparatus according to a preferred embodiment of the present invention. The control unit **5500** comprises a frame memory **5520**, an SLM controller **5530**, a sequencer **5540**, a video image analysis unit **5550**, a light source control unit **5560**, and a light source drive circuit **5570**.

The sequencer **5540** includes a microprocessor to control the operation timing of the entire control unit **5500** and the spatial light modulators **5100**.

In one exemplary embodiment, the frame memory **5520** one frame of input digital video data **5700** received from an external device (not shown figure) connected to a video signal input unit **5510**. The input digital video data **5700** is updated, in real time, every time the display of one frame is completed.

The SLM controller **5530** processes the input digital video data **5700** read from the frame memory **5520**, as described later. The SLM controller **5530** separates the read data into a plurality of sub-fields **5701** through **5703**, and outputs them to the spatial light modulators **5100** as binary data **5704** and non-binary data **5705**, which are used for implementing an ON/OFF control and an oscillation control (which are described later) of a mirror **5112** of the spatial light modulator **5100**.

The sequencer **5540** outputs a timing signal to the spatial light modulators **5100** in sync with the generation of the binary data **5704** and non-binary data **5705** at the SLM controller **5530**.

The video image analysis unit **5550** outputs a video image analysis signal **6800** used for generating various light source patterns (which are described later) corresponding to the input digital video data **5700** inputted from the video signal input unit **5510**.

The light source control unit **5560** controls the light source drive circuit **5570** to control the operation of the adjustable light source **5210** by using a light source profile control signal in emitting the illumination light **5600**. The light source profile control signal is generated from the video image analysis signal **6800** by the video image analysis unit **5550** using data from the light source pulse patterns **5801** through **5811** generated by the sequencer **5540**, as will be further described below.

The light source drive circuit **5570** operates to drive the red **5211**, green **5212** and blue **5213** laser light sources of the adjustable light source **5210** to emit light. The light source generates the light source pulse patterns **5801** through **5811** (which are described later) received from the light source control unit **5560**.

FIG. **3**B is a functional block diagram exemplifying the configuration of a control unit comprised in a multi-panel projection apparatus according to the present embodiment.

The control unit **5502** comprises a plurality of SLM controllers **5531**, **5532** and **5533** that are used for controlling each of the spatial light modulators **5100**. Each of the modulators is implemented for modulating the respective colors R, G and B, and the configuration of the controllers is the main difference between the control unit **5502** and the control unit **5500** described in FIG. **3**A.

Specifically, each of the SLM controllers **5531**, **5532** and **5533** is implemented to process the modulation of its respective color R, G, and B. Each modulator is supported on the same substrates as those of the respective spatial light modulators **5100**. This configuration makes it possible to place the individual spatial light modulators **5100** and the corresponding SLM controllers **5531**, **5532** and **5533** close to each other, thereby enabling a high-speed data transfer rate. Furthermore, a system bus **5580** is used to connect the frame memory **5520**, light source control unit **5560**, sequencer **5540** and SLM controllers **5531** through **5533**, in order to speed up and simplify the connection path of each connecting element.

FIG. **4**A is a circuit block diagram for illustrating the configuration of the light source drive circuit **5570** (i.e., the light source drive circuits **5571**, **5572** and **5573**) according to the present embodiment.

The light source drive circuit shown in FIG. **4**A comprises a plurality of constant current circuits **5570***a* (i.e., I $(R,G,B)_1$ through I $(R,G,B)_n$) and a plurality of switching circuits **5570***b* (i.e., switching circuits SW $(R,G,B)_1$ through SW $(R,G,B)_n$), corresponding to the respective constant current circuits **5570***a*, in order to generate the desired light intensities. The light emissions are shown as P_1 through P_n for the light source optical system **5200** (i.e., the red **5211**, green **5212**, and blue **5213** laser light sources).

The switching circuits **5570***b* each carries out a switching in accordance with a desired emission profile of the light source optical system **5200** (i.e., the red **5211**, green **5212** or blue **5213** laser light source).

The setup values of the output current of the constant current circuits **5570***a* (i.e., constant current circuits I $(R,G,B)_n$), when the gray scale of the emission intensity of the light source optical system **5200** is designated at N bits (where N≧n), are as follows:

$$I(R,G,B)_1=I_{th}+LSB$$

$$I(R,G,B)_2=LSB+1$$

$$I(R,G,B)_3=LSB+2$$

$$\cdots$$

$$\cdots$$

$$I(R,G,B)_n=MSB$$

In this exemplary embodiment, a gray scale display is controlled on the basis of the emission intensity. A similar gray scale display is achievable even if the emission period (i.e., an emission pulse width) and the emission interval (i.e., an emission cycle) are variable.

The relationship between the emission intensity Pn of the adjustable light source and drive current for each color in this case is as follows. Note that "k" is an emission efficiency corresponding to the drive current:

$$P_1=k*(I_{th}+I_1)$$

$$P_2=k*(I_{th}+I_1+I_2)$$

$$\cdots$$

$$\cdots$$

$$P_n=k*(I_{th}+I_1I_2+\ldots+I_{n-1}+I_n)$$

FIG. **4**B is a block diagram showing a modified embodiment of the configuration of the light source drive circuit according to the present embodiment.

For simplicity, FIG. **4**B denotes the constant current circuits **5570***a* (I $(R,G,B)_1$ through I $(R,G,B)_n$) as I_1 through I_n and the switching circuits **5570***b* (SW $(R,G,B)_1$ through SW $(R,G,B)_n$) as switching circuits **5570***b* (SW_1 through SW_n).

As described later, the light source drive circuits **5570**, according to the present embodiment, are configured to control the individual constant current circuit **5570***a* (i.e., I $(R,G,B)_1$ in this case) to supply a current value equivalent to the threshold current I_{th} of the light source optical system **5200**. Alternately, the individual constant current circuit supplies a current close to the aforementioned threshold current, as a bias current I_b when a semiconductor laser or similar light source is used as the light source optical system **5200**. By using a high-speed current drive, the respective switching operations of the light source drive circuits **5570** are stabilized to provide a high-speed emission.

The light source drive circuits **5570** (i.e., the light source drive circuits **5571**, **5572**, and **5573**) shown in FIG. **4**B comprise a bias current circuit **5570***c*, which are continuously connected to the light source optical systems **5200** (i.e., the red **5211**, green **5212**, and blue **5213** laser light sources) and which are used for applying a bias current I_b, in addition to the constant current circuits **5570***a*

Furthermore, the connection of the constant current circuits **5570***a* to the light source optical systems **5200** is configured through a switching circuit **5570***d* (SW_{pulse}) formed on the downstream side of the switching circuits **5570***b*.

In the case of the configuration shown in FIG. **4**B, the relationship between the emission intensity P_n and the drive current of the adjustable light source for each wavelength is as follows, where "k" is the emission intensity in terms of drive current:

$$P_b=k*I_b(I_b\infty I_{th})$$

$$P_1=k*(I_{th}+I_1)$$

$$P_2=k*(I_{th}+I_1+I_2)$$

$$\cdots$$

$$\cdots$$

$$P_n=k*(I_{th}+I_1+I_2+\ldots+I_{n-1}+I_n)$$

Specifically, the relationship between each switching operation and emission output is as follows:

$$SW_{pulse}=\text{OFF}:P_b=k*I_b\approx 0[mW]\ (\text{where } I_b\approx I_{th})$$

$$SW_1:P_1=k*(I_b+I_1)$$

$SW_2:P_2=k^*(I_b+I_1+I_2)$

. . .

. . .

$SW_n:P_n=k^*(I_b+I_1+I_2+\ldots I_{n-1}+I_n)$

With this, it is possible to attain an emission profile possessing an emission intensity P_b that is nearly zero.

FIG. **4**B shows an embodiment wherein the switching circuits **5570***d* can carry out a circuit operation unaffected by a drive current switching over, which may be caused by the switching circuits **5570***b* (SW_1 through SW_n). Each of the switching circuits **5570***b* is connected to the respective constant current circuits **5570***a*. Particularly, a further function is carried out in that when the adjustable light source **5210** is not emitting light, the switching circuits (SW_1 through SW_n) are switched over adjustable light source.

While the bias current value is designated at a fixed current value in the configuration of FIG. **4**B, it is also possible to connect the constant current circuit **5570***c* to the light source control unit **5560** and allow a variable bias current.

FIG. **5** is a diagram showing the relationship between the applied current I and the emission intensity P_n of the light source drive circuit shown in the above described FIG. **4**A.

FIG. **6** is a diagram showing the relationship between the applied current I and the emission intensities P_b and P_n of the constant current circuit **5570***a* of the light source drive circuit shown in the above described FIG. **4**B.

Note that the descriptions for FIGS. **4**A and **4**B have been provided for the case of changing the emission profiles of the adjustable light source for each sub-frame corresponding to each gray scale bit. If the display gray scale function of the spatial light modulator **5100** is used in parallel, the number of required levels of electrical current decreases, thus reducing the number of constant current circuits **5570***a* and switching circuits **5570***b*. It is therefore possible to obtain the number of gray scales equal to, or higher than, the gray scales achievable through the modulation process of the spatial light modulator **5100**.

The following detail description explains the configuration of the spatial light modulator **5100** according to the present embodiment.

The spatial light modulator **5100** according to the present embodiment is a deflectable mirror device with an array of mirror elements. FIG. **7** is a schematic circuit diagram exemplifying the layout of the internal configuration of the spatial light modulator **5100** according to the present embodiment. FIG. **8** is a cross-sectional diagram of an individual pixel unit implemented in the spatial light modulator **5100** according to the present embodiment. FIG. **9** is a side cross sectional view diagram exemplifying the configuration of an individual pixel unit constituting the spatial light modulator **5100** according to the present embodiment.

FIG. **7** shows an exemplary embodiment of the mirror device **5100** that includes a mirror element array **5110**, column drivers **5120**, row line decoders **5130** and an external interface unit **5140**. The external interface unit **5140** includes a timing controller **5141** and a selector **5142**. The timing controller **5141** controls the row line decoder **5130** on the basis of a timing signal from the SLM controller **5530**. The selector **5142** supplies the column driver **5120** with digital signal incoming from the SLM controller **5530**. A plurality of mirror elements are arrayed as a mirror element array **5110** at the positions aligned with individual bit lines **5121**. The bit lines are vertically extended from the column drivers **5120**, crossing individual word lines **5131**. The word lines are horizontally extended from the row line decoders **5130**.

As shown in FIG. **8**, the individual mirror element **5111** includes a mirror **5112** supported on a substrate **5114** by a hinge **5113** to deflect within a range of deflection angles. The mirror **5112** is covered with a cover glass **5150** for protection.

An OFF electrode **5116** (and an OFF stopper **5116***s*) and an ON electrode **5115** (and an ON stopper **5115***s*) are placed symmetrically across the hinge **5113** on the substrate **5114**.

The OFF electrode **5116** attracts the mirror **5112** with a coulomb force by applying a predetermined voltage and tilts the mirror **5112** to make contact with the OFF stopper **5116***s*. This causes the incident light **5601**, incident to the mirror **5112**, to be reflected to the light path of an OFF position, offset from the optical axis of the projection optical system **5400**. The state of a mirror (or mirror element) in this condition is called the OFF state.

The ON electrode **5115** attracts the mirror **5112** with a coulomb force by applying a predetermined voltage and tilts the mirror **5112** to make contact with the ON stopper **5115***s*. This causes the incident light **5601**, incident to the mirror **5112**, to be reflected to the light path of an ON position, matching the optical axis of the projection optical system **5400**. The state of a mirror (or mirror element) in this condition is called the ON state.

Furthermore, in FIG. **9**, one mirror element **5111** comprises a mirror **5112**, an elastic hinge **5113** for retaining the mirror **5112**, address electrodes **5115** and **5116**, and two memory cells, i.e., a first memory cell **5115***a* and a second memory cell **5116***a*, both of which apply a voltage to the address electrodes **5115** and **5116** in order to control the mirror **5112** under a desired deflection state.

The first and second memory cells **5115***a* and **5116***a* each has a dynamic random access memory (DRAM) structure comprising gate transistors (i.e., gate transistors **5115***c* and **5116***c*) and a capacitor (i.e., ON capacitor **5115***b* and OFF capacitor **5116***b*) in this configuration. The structures of the individual memory cells **5115***a* and **5116***a* are not limited as such and may instead be, for example, a static random access memory (SRAM) structure or the like.

Furthermore, the individual memory cells **5115***a* and **5116***a* are connected to the respective address electrodes **5115** and **5116**, a COLUMN line **1**, a COLUMN line **2** and a ROW line.

In the first memory cell **5115***a*, the gate transistor **5115***c* is connected between the address electrode **5115** and ROW line, and between the COLUMN line **1** and ROW line. An ON capacitor **5115***b* is connected between the address electrode **5116** and GND (i.e., the ground). Likewise in the second memory cell **5116***a*, a gate transistor **5116***c* is connected between the address electrode **5116** and COLUMN line **2**, and between the COLUMN line **2** and ROW line. An OFF capacitor **5116***b* is connected between the address electrode **5116** and GND.

Controlling the signals on the COLUMN line **1** and ROW line applies a predetermined voltage to the address electrode **5115**, thereby making it possible to tilt the mirror **5112** towards the address electrode **5115**. Likewise, controlling the signals on the COLUMN line **2** and ROW line applies a predetermined voltage to the address electrode **5116**, thereby making it possible to tilt the mirror **5112** towards the address electrode **5116**.

Specifically, the ON/OFF of the gate transistors **5116***c* and **5115***c* are controlled by ROW line. Specifically, the mirror elements **5111** disposed on one horizontal row along a designated ROW line are simultaneously selected, and the charging and discharging of electrical charge to and from the ON capacitor **511***b* and **5116***b* are controlled, thereby turning ON and OFF the mirrors **5112** of individual mirror elements on one horizontal row.

Note that a drive circuit for each of the memory cells **5116***a* and **5116***a* is commonly formed in the device substrate **5114**. Controlling the respective memory cells **5115***a* and **5116***a* in accordance with the signal of image data enables control of the deflection angle of the mirror **5112** and carries out the modulation and reflection of the incident light.

Next is a description of the deflecting operation of the mirror **4003** of the mirror element **4001** shown in FIGS. **8** and **9** with reference to FIGS. **10**A, **10**B and **10**C.

FIG. **10**A is a diagram depicting the state in which an incident light is reflected towards a projection optical system by deflecting the mirror of a mirror element.

FIG. **9** shows the memory cells **4010***a* and **4010***b* (not shown here) storing the signal (**0**,**1**) which applies a voltage of "0" volts to the address electrode **4008***a* of FIG. **10**A and applies a voltage of Ve volts to the address electrode **4008***b*. As a result, the mirror **4003** is deflected from a deflection angle of "0" degrees, i.e., the horizontal state, to that of +12 degrees, attracted by a coulomb force, in the direction of the address electrode **4008***b* to which the voltage of Ve volts is applied. This causes the incident light to be reflected by the mirror **4003** towards the projection optical system (known as the ON light state or ON state).

Specifically the present patent application defines the deflection angles of the mirror **4003** as "+" (positive) for clockwise (CW) direction and "−" (negative) for counterclockwise (CCW) direction, with "0" degrees as the initial state of the mirror **4003**. Furthermore, an insulation layer **4006** is provided on the device substrate **4004**, and a hinge electrode **4009**, connected to the elastic hinge **4007**, is grounded through the insulation layer **4006**.

FIG. **10**B is a diagram depicting the state in which the incident light is not reflected toward a projection optical system by deflecting the mirror of a mirror element. With a signal (**1**, **0**) stored in the memory cells **4010***a* and **4010***b* (not shown here), illustrated in detail in FIG. **9**, a voltage of Ve volts is applied to the address electrode **4008***a*, and "0" volts is applied to the address electrode **4008***b*. As a result, the mirror **4003** is deflected from a deflection angle of "0" degrees, i.e., the horizontal state, to that of −12 degrees in the direction of the address electrode **4008***a*, to which the voltage of Ve volts is applied. This causes the incident light to be reflected by the mirror **4003** in a direction away from that of the light path towards the projection optical system (known as the OFF light state or OFF state).

FIG. **10**C is a diagram depicting the state in which incident light is reflected towards and away from a projection optical system by the repeated free-oscillation of the mirror of a mirror element.

In FIG. **10**C, a signal (**0**, **0**) stored in the memory cells **4010***a* and **4010***b* (not shown here) applies a voltage of "0" volts to the address electrodes **4008***a* and **4008***b*. As a result of zero voltage applied to the electrodes, the coulomb force that has been generated between the mirror **4003** and address electrode **4008***a* or **4008***b* is withdrawn so that the mirror **4003** is operated in a free oscillation within the range of the deflection angles ±12 degrees, in accordance with the property of the elastic hinge **4007** (known as the free oscillation state). During the free oscillation, the incident light is reflected towards the projection optical system only when the mirror **4003** is within the range of a specific deflection. The mirror **4003** repeats the free oscillations, changing over frequently between the ON light state and OFF light state. Controlling the number of changeovers makes it possible to finely adjust the intensity of light reflected towards the projection optical system.

The total intensity of light reflected during free oscillation towards the projection optical system is certainly lower than the intensity that is produced when the mirror **4003** is continuously in the ON light state and higher than the intensity that is produced when it is continuously in the OFF light state. Specifically, it is possible to produce an intermediate intensity between the intensities of the ON light state and OFF light state. Therefore, by finely adjusting the light intensity as described above, a higher gradation image can be projected than with the conventional technique.

Although not shown in a drawing, an alternative configuration may be such that only a portion of light is made to enter the projection optical system by reflecting an incident light in the initial state of a mirror **4003**. Configuring as such makes the reflection light enter the projection optical system with a higher intensity than when the mirror **4003** is continuously in the OFF light state and with a lower intensity than when the mirror **4003** is continuously in the ON light state, thus controlling the mirror **4003** to operate in an intermediate light state.

A mirror device with an oscillation state and an intermediate light state is more preferable than the conventional mirror device capable of controlling in only two states (i.e., the ON light state and OFF light state) as a device for displaying a next generation image with a higher level of gradation.

The following are descriptions of various preferred embodiments, with the configurations and operations of the projection apparatuses shown in FIGS. **1** through **9** described above. Note that the same alphanumeric designations are assigned to the same constituent component or signal as those already described, and no duplicate description is provided in the following descriptions.

Embodiment 1

FIGS. **11** and **12** are timing diagrams for illustrating the operation sequences of a projection apparatus according to a preferred embodiment of the present invention.

A projection apparatus according to the present embodiment may be implemented according the apparatuses described as a single-panel projection apparatus **5010**, that includes the optical system as depicted in the above described FIG. **1** and the control system (i.e., the control **5500**) as that depicted in the above described FIG. **3**A. The image projection apparatuses carry out a projection display of a color image by implementing a color sequential display method.

Specifically, the SLM controller **5530** of the control unit **5500** as that implemented by the projection apparatus **5010** generates a light source profile control signal **5800** based on the input digital video data **5700**. The light source profile control signals are then inputted to a light source control unit **5560** through a sequencer **5540**A.

The light source control unit **5560** controls the pulse width to project pulse emission from the red laser light source **5211**, green laser light source **5212** and blue laser light source **5213** of a light source **5210** as flashing lights. The speed of flashing rates controlled by the light source profile control signal **5800** for switching between different colors of laser lights has a higher speed than the rate of state changes of the mirrors **4003** implemented in spatial light modulator **5100** for modulating the lights of different colors. Specifically, FIG. **11** shows the light source control unit **5560** controls the light source **5210** to turn on only for the period when a mirror is operated at a "stable ON" time shown as Tnet i.e., a second time length. The stable ON time is shorter than one ON operation period shown as the mirror ON period T**0**, i.e., a first time length, of the mirror **4003** as indicated in the mirror ON/OFF control pattern **8021**.

Therefore, the mirror ON period T**0** includes a rise time tr, a mirror stable ON time Tnet and a fall time tf. The mirror **4003** is unstable during the period of the rise time tr and fall time tf. The operation of the mirror during these unstable ON time periods generates a noise in reflection light **5602**.

In order to minimize the adverse effects of the reflection during the unstable ON time periods, the present embodiment implements a light source control to turn on the light source **5210** only for a period of time of the mirror stable ON time Tnet. The light source is controlled by a light source pulse pattern **8010**. With properly arranged light source control signals, the reflection light during the unstable ON periods including the rise time tr and fall time tf are eliminated because the light source is turned off during these periods. Therefore, accurate control of the intensity of the reflection light **5602** is achievable by controlling the projection periods the incident light **5601** from the light source incident to the spatial light modulator **5100**.

Furthermore, the control method for controlling the mirror **4003** can also be applied to an apparatus implemented with an oscillation control. With oscillation control schemes, in addition the ON/OFF mirror states as depicted in FIG. **11**, the mirror **4003** is controlled to oscillate between the ON state and OFF state. In an oscillation state of the mirror **4003**, the light source pulse pattern **8010** is controlled to have variable pulse width. The light source pulse width T**2** and a light source pulse width T**3** are illustrated in FIG. **12**. Therefore, compared with the light source that is kept on continuously, the intensity of the reflection light **5602** can be flexibly adjusted to achieve to more an accurate control the light intensity to coordinate with the oscillations of the mirrors.

FIG. **12** depicts the intensity of the reflection light **5602** that is controllable by controlling the length of time in turning on the light source when the mirror **4003** is operated at an ON state. The length of time when a mirror **4003** is operated at an ON state is denoted as a period T**0** and the light intensity reflected from the mirror by keeping the light source **5210** continuously turned on is defined as one unit. In this embodiment, the light source **5210** is controlled to project lights as pulse emission. The light source control signal has a light source pulse width T**2**. The pulse width T**2** is smaller than the pulse width T**0** when the mirror is operated at an ON state. Furthermore, the center portion of FIG. **85** shows a mirror ON period T**0** in which the mirror **4003** is in an oscillation state. The mirror is controlled to oscillate in accordance with a mirror oscillation control pattern **8022**. Therefore, the intensity of the reflection light is controlled at ⅓ unit of the reflection light **5602** (as shown at the center of FIG. **12**). Alternately, the light source **5210** is controlled to project pulse emission by controlling the light source with a light source pulse width T**3** that is even smaller than the light source pulse width T**2**. Therefore, the intensity of the reflected light can be controlled at ¼ unit of the reflection light **5602** (as shown on the left end of FIG. **12**).

With the reduced amount of light that is controllable, accurate control of the intensity of the reflection light **5602** (i.e., projection light **5603**) down to an amount of about ⅓ unit and ¼ unit is achievable by controlling the pulse emission of the light source **5210** with different pulse width. The pulse width may be flexibly controlled in a period in which the change amount of the intensities of the reflection light **5602** reflected from the mirror **4003**. Generally, the smallest amount of controllable light is achievable when the mirror **4003** of the spatial light modulator **5100** is operated in the oscillation state.

The following is a description of an exemplary embodiment for improving a degree of freedom in a color expression. Improvements of the color temperature and color balance are achievable for a projection image by controlling the pulse emission projection of the light source **5210** without changing the input digital video data **5700**.

Step 1: the control signal inputted to SLM controller **5530** as control words, shown as one frame of input digital video data **5700**, are divided into R, G and B pieces of data, noted as "RBG data" hereinafter.

Step 2: the SLM controller **5530** further divides the RGB data into a plurality of pieces, e.g., 31 pieces when the input data is for a 5-bit gray scale; 127 pieces when the input data is for 7-bit gray scale. FIG. **13** further shows the mirror ON/OFF control patterns **8021**.

Step 3: the SLM controller **5530** processes the RGB data now divided according to the R, G and B colors as sub-fields, rearranges the sub-fields in order of R, G and B, and generates a one-frame control signal (Data) (i.e., a mirror ON/OFF control pattern **8021***a* shown in FIG. **13**) for controlling the spatial light modulator **5100**.

Step 4: the SLM controller **5530** generates a control signal, i.e., a light source pulse pattern **8011** shown in FIG. **13**, for the light source **5210**. The light source pulse pattern **8011** inputted to the light source thus controls all the red laser light source **5211**, green laser light source **5212** and blue laser light source **5213** to emit the respective colors R, G and B for the respective periods of individual sub-fields.

Furthermore, the SLM controller **5530** generates the light source pulse pattern **8011** to increase the emission time length of the light source of the main color for image display in each sub-field and decreases the emission time lengths of the light source of the remaining colors. As an example, for displaying the color red (R) of the light source pulse pattern **8011** of the sub-field as shown in FIG. **13**, the light source pulse pattern **8011** is generated to shorten a green light source turn-on time TG (e.g., a pulse width) and a blue light source turn-on time TB (e.g., a pulse width) relative to a red light source turn-on time TR (e.g., a pulse width) that is the main color.

Furthermore, the exemplary embodiment provides controllable lengths of time for controlling the red light source turn-on time TR, green light source turn-on time TG and blue light source turn-on time TB. These controllable lengths of time are the respective emission time lengths of the light sources of the main color (i.e., red in this case) and other colors, are set within the mirror stable ON time Tnet. Other then the main color, the lengths of time are controlled to have a shorter length than the control unit time (i.e., the mirror ON period T**0**) of the mirror **4003** implemented in the spatial light modulator **5100**. These subfields for each color are controlled to carry out a sequential emission of the respective colors R, G and B, or two colors from among R, G and B during the display period of sub-frames on an as required basis.

FIG. **13** shows the exemplary embodiment wherein the sequential emissions of R, G and B and the length of the red light source is twice the lengths of the turn-on time TR, green light source turn-on time TG and blue light source turn-on time TB during the mirror stable ON time Tnet.

Step **5**: the SLM controller **5530** receives and applies the light source pulse pattern **8011** corresponding to the light source profile control signal **5800** to control the light source **5210** and also controls the spatial light modulator **5100** using the above described control signal (Data) of the spatial light modulator **5100**.

According to the control processes, the projection apparatus **5010** controlled with a color sequential method using the input digital video data **5700** and implementing the projection optical system **5400** to project a color video image on a screen **5900** using the color sequential display method.

Effect 1 of the Present Embodiment

Specific benefits of the present embodiment are summarized and discussed below. Changing the ratio of the time lengths (i.e., the red light source turn-on time TR, green light source turn-on time TG and blue light source turn-on time TB) of the respective color lights, i.e., R, G and B, emitted during the display period of sub-frames can achieve the desired color balance of the color video image by using the projection light **5603** projected on the screen **5900** by way of the projection optical system **5400**. The color balance is achieved without changing a control signal (Data) for the spatial light modulator **5100**.

FIG. **14** is a timing diagram for illustrating an exemplary length of time TR for turning on the red light source as the main color for the period of displaying sub-frames relative to the green light source turn-on time TG and blue light source turn-on time TB. For simplicity, FIG. **14** depicts the sequential RGB turning on times in one cycle of emission during the mirror stable ON time Tnet. According to FIG. **14**, the length of the turning-on time during the mirror stable ON time Tnet for each color, i.e., the red light source turn-on time TR, green light source turn-on time TG and blue light source turn-on time TB are set at a constant ratio.

Alternatively, each of the red light source turn-on time TR, green light source turn-on time TG and blue light source turn-on time TB can be set at respectively a predetermined time length.

Furthermore, the red light source turn-on time TR, green light source turn-on time TG and blue light source turn-on time TB can respectively be controlled as flexibly adjustable time lengths. Or, by changing the ratios appropriately among the red light source turn-on time TR, green light source turn-on time TG and blue light source turn-on time TB can further adjust the color balance. Specifically, the changing the ratios among the red light source turn-on time TR, green light source turn-on time TG and blue light source turn-on time TB, is equivalent to changing the color coordinates on a chromaticity diagram (not shown in a drawing herein). The image projection apparatus enables the control system to control the color temperature of a color video image displayed on the screen **5900** using the projected light **5603** by appropriately changing the ratio among the red light source turn-on time TR, green light source turn-on time TG and blue light source turn-on time TB.

Effect 2 of the Present Embodiment

It is possible to enhance brightness by controlling the green light source turn-on time TG and blue light source turn-on time TB to overlap with the time period of the red light source turn-on time TR during the display period of one main color (i.e., red in this case) according to the light source pulse pattern **8011** shown in the above described FIG. **13**.

FIG. **15** is a timing diagram for illustrating the principle of improving the brightness. For simplicity, FIG. **15** depicts a display of one cycle of R, G and B during a mirror stable ON time Tnet similar to the above-described FIG. **14**.

Specifically, the green light source turn-on time TG (i.e., white light/green component TWG) and blue light source turn-on time TB (i.e., white light/blue component TWB) are controlled to overlap with the time period of the main red light source turn-on time TR during the mirror stable ON time Tnet. The colors are synthesized with the white light/red component TWR contained in the red light source turn-on time TR, thereby generating a white component to proportionately enhance the brightness of the projection image.

FIG. **15** thus illustrates an enhancement in the brightness by increasing a white component in the case of the ON/OFF control for the mirror **4003**. Enhancements of the brightness may also be achieved by combining the ON/OFF control of the mirror **4003** with an oscillation control thereof as shown in FIG. **16**.

Specifically, FIG. **16** depicts a light source pulse pattern **8012** to increase a white light component by combining other white light/green component TWG and white light/blue component TWB. This is achieved by controlling the mirror **4003** for combining the ON/OFF control with an oscillation control in accordance with a mirror control signal profile **8020** that includes a mirror ON/OFF control pattern **8021** and a mirror oscillation control pattern **8022**.

Specifically, FIG. **16** illustrates the light source pulse pattern **8012** for controlling the white light/green component TWG and white light/blue component TWB to overlap with the main red light source turn-on time TR during the ON/OFF control period corresponding with the mirror ON/OFF control pattern **8021**. The white light/red component TWR has a light intensity balances with the two color components simultaneously projected during the period of the mirror oscillation control pattern **8022**.

FIG. **17** depicts the control process of a 6-bit gray scale display carried out with a 3-bit ON control and a 3-bit oscillation control in order to display digital video image data (i.e., the input digital video data **5700**) in 6-bit gray scale for each color.

There are three bit for each color for controlling the mirror **4003** to operate at an ON state in the seven ON periods during the display period of one frame of a display video image according to the mirror ON/OFF control pattern **8021**. Specifically, the mirror projects in each ON period a brightness equivalent to the LSB of the upper 3-bit of respective colors according to the input data during the respective ON period. In the ON periods for each color, the mirror **4003** is repeatedly operated at an ON state multiple times (i.e., two times in this configuration) of the pulse emission of the red laser light source **5211**, green laser light source **5212** and blue laser light source **5213** of the respective colors R, G and B for a shorter time length than the ON period. The ratio of the pulse emission of the respective colors are set to maximize the ratio of the main color displayed through reflecting from a mirror **4003** that is controlled to synchronously operate at an ON state. Following each ON time for different colors, the mirror oscillation control pattern **8022** controls the mirror to operate in one oscillation state and the pulse emission (i.e., white light/red component TWR) of the main color (i.e., red (R) is projected at the beginning of the frame, as shown in FIG. **17**, with the main color displayed during the previous ON time. The main color display time during last cycle has a shorter time (i.e., a second time length), that shorter than the oscillation time length (i.e., a mirror oscillation period Tosc; first time length).

This control process causes a white component projected as the sum of the pulse emission (e.g., white light/red component TWR) corresponding to the oscillation state and the plus emissions (i.e., the white light/green component TWG and white light/blue component TWB) of the two lights (i.e., G and B). The projection light is brighter than the main color emitted during the previous ON time, thereby increasing the brightness of the video image. After the mirror **4003** is controlled to operate at an ON state, the mirror is controlled to operate at an oscillation state according to the 3-bit for the respective colors, that is, 7 times of oscillation, during the display period of one frame.

Specifically, the brightness is therefore equivalent to the LSB of the lower 3-bit of each color of the input data in each oscillation period. In each oscillation control, the pulse projections of a laser light source of either color of R, G and B project to the mirror **4003** during length of time that is shorter than each oscillation time length (i.e., the mirror oscillation period Tosc).

The control process described above applies a 6-bit gray scale display control for each color during the display period of one frame.

Meanwhile, FIG. **18** is a timing diagram for showing the light source pulse pattern **8012** and mirror control signal profile **8020** for carrying out a 6-bit gray scale display control with a 3-bit ON control and a 3-bit oscillation control in order to display the input digital video data **5700** in 6-bit gray scale for each color. Specifically, the spatial light modulator **5100** applies the mirror ON/OFF control pattern **8021** for carrying out the mirror ON time control includes 3-bit ON period for each color. Therefore, during the display period of one frame of a display video image there are 7 ON times for each color. Specifically, with such a control process, the brightness is equivalent to the LSB of the higher 3-bit of each color of the input digital video data **5700** inputted during each ON period.

During each ON period the pulse projection from the red **5211**, green **5212** and blue **5231** laser light source of the respective colors R, G and B projects light to the mirror **4003** a plurality of times according to the mirror ON/OFF control pattern **8021**, i.e., two times in the example of FIG. **18**. The length of ON time has a shorter time length (i.e., the mirror stable ON time Tnet) than the ON period of the mirror. The ratio of the pulse width for projecting different colors is set to maximize the pulse width of the main color of display by controlling a mirror **4003** operated at an ON state.

Subsequent to the ON time corresponding to the mirror ON/OFF control pattern **8021** for each color, the mirror is controlled to operate at one oscillation state according to the mirror oscillation control pattern **8022**. The pulse width of the main color (i.e., R in the example of the head side of FIG. **91**) displayed in the previous ON time is set with a shorter time length than the oscillation time length (i.e., the mirror oscillation period Tosc).

The color balance of the display video image is adjusted by the ratio of the pulse width for each color (i.e., the white light/red component TWR) corresponds to the oscillation state. The color balance is further adjusted by taking into account the pulse width of two colors other than the main color emitted during the previous ON time, i.e., G and B, or the white light/green component TWG and white light/blue component TWB) of two colors. Subsequently the mirror is controlled to operate at an ON state, the mirror **4004** is controlled to operate at an oscillation state according to a 3-bit oscillation control signal for the respective colors, that is, 7 times of oscillation, during the display period of one frame. Therefore, a brightness equivalent to the brightness according to the LSB of the lower 3-bit of each color of the input data is achieved during the respective oscillation periods.

In the respective periods when the mirror is operated in the oscillation state, the mirror **4003** is irradiated by repeating a plurality of times (i.e., one time in this case) of pulse emission (i.e., the white light/blue component TWB, white light/red component TWR and white light/green component TWG) of laser light sources of three colors R, G and B. The pulse emission for each color is projected in a shorter time length than the respective oscillation time lengths.

The ratio of the pulse emission of the respective colors is set to maximize the main color light projection by controlling a mirror **4003** operated in an oscillation state. The pulse emission of the mirror is controlled to be at a timing coinciding with the center of the oscillation state. The color balance of the display video image is adjusted by adjusting the ratio of the reflection light intensities of the light of the colors R, G and B and adjusting the intensities reflected during the oscillation period. The control processes as described above allows the flexibility of adjusting the color balance of a displayed video image in addition to a 6-bit gray scale display for each color during the display period of one frame.

Embodiment 2

As described above, an image projection apparatus employs a spatial light modulator **5100** implemented as a mirror device. According to the present embodiment, the mirror device is configured to carry out a linear gray scale display that is different from a conventional display apparatus, such as a cathode ray tube (CRT) display.

Therefore, FIG. **19** illustrates a gamma correction; an input data γ curve **7700***a* is applied to a piece of input digital video data **5700** at the transmission source (i.e., where the imaging is carried out). Assuming a display on a CRT, as shown in FIG. **19**, a projection apparatus comprising a display device other than a CRT is required to restore the characteristic of a gray scale display to the original state (e.g., a conversion line **7700**L for performing a linear conversion of the input data signal and brightness signal). This is done by means of a correction such as a gamma correction curve **7700***b*, or by a variety of gamma corrections in accordance with the respective characteristics of projection apparatuses **5010**, **5020**, **5030** and **5040**.

In such a case, a mathematical operation related to the input digital video data **5700**, as it is performed in a conventional display apparatus, causes the circuit scale of the control unit **5500** to increase, leading to a higher production cost.

The present embodiment is configured so that the above described video image analysis unit **5550** changes the emission pattern of the illumination light, emitted from the adjustable light source **5210**, to the profile as indicated by a gamma correction light intensity variation **7800***a* so as to correspond to the above described gamma correction curve **7700***b*, as illustrated in FIG. **20**. Thereby, a linear gray scale display, as indicated by the conversion line **7700**L, is attained by negating the influence of the input data γ curve **7700***a* performed at the transmission source, without requiring a mathematical operation of the input digital video data **5700**.

Note that this configuration makes it possible not only to restore the linearity by negating the influence of the input data γ curve **7700***a*, but also to change, intentionally and nonlinearly, the emission intensities of the adjustable light source **5210** within one frame, as described below. This enables various and highly precise gray scale displays, exceeding the original gray scale capability of the spatial light modulator **5100** adjustable light source.

For example, a video image output (i.e., input digital video data **5700**) contains various scenes, such as a dark scene, a bright scene, a generally bluish scene, and a generally reddish scene, such as sunset. The projection apparatus according to the present embodiment is configured to control the gray scale of the emission output of the adjustable light source **5210** optimally for each scene (with actual control carried out in units of frame), thereby making it possible to attain higher quality video images than with the conventional method.

When a gamma correction for input digital video data **5700** (i.e., an input data γ curve **7700***a*) is implemented by means of a temporal change in emission intensities of the adjustable light source **5210** as described above, a precise emission control of the adjustable light source **5210** is difficult if an ON/OFF control of the mirror **5112** is carried out through a pulse width modulation (PWM,) which uses binary data **7704** included in the input digital video data **5700** adjustable light source.

Thus, the SLM controller **5530**, according to the present embodiment, is configured to carry out an ON/OFF control for the mirror **5112** using non-binary data **7705** obtained by converting the binary data **7704**, as shown in FIGS. **21** and **22**.

FIG. **21** illustrates 1.) The generation of non-binary data **7705** (which is a bit string with each digit being of equal weight) from the binary data **7704** comprising, for example, 8-bit "10101010" and 2.) The mirror **5112** is turned ON the only for a period when the bit string continues.

Note that FIG. **21** illustrates 1.) The conversion of non-binary data **7705** so that the bit string is packed forward within the display period of one frame, and 2.) The turning ON of the mirror **5112** for a predetermined period in accordance with the bit string number starting from the beginning of a frame display period.

Furthermore, FIG. **22** illustrates the conversion of binary data **7704** (shown in FIG. **21**) into a bit string of non-binary data **7705** with the digits packed backward. In this case, the mirror **5112** is turned ON only in the period of time corresponding to the bit string number starting from the middle of a frame display period until the end.

When the ON/OFF of the mirror **5112** is controlled by the non-binary data **7705** as described above, the ON period of the mirror **5112** becomes continuous, and therefore, control of the emission intensity of the adjustable light source **5210** synchronously with the aforementioned ON period be more easily achieved.

FIG. **23** illustrates 1.) The brightness input of 8-bit non-binary data **7705** into, for example, four steps, i.e., 64, 128, 192 and 255, as shown in the upper rows of FIG. **23**, and 2.) Obtaining a gamma correction curve **7700***c*, as shown in the lower row of the drawing, through a four-step control of the output intensity of the adjustable light source **5210** in response to the each of the aforementioned levels, as indicated by a light source pulse pattern **7801** shown in the middle row of the drawing.

For simplicity, while FIG. **23** illustrates the control process in four steps, a further minute grouping of the non-binary data **7705** makes it possible to obtain a smoother curve than the gamma correction curve **7700***c*.

Note that the example of FIG. **23** shows that the correction amount of the gamma correction curve **7700***c* is less bright when compared with the conversion line **7700**L. Accordingly, the emission pattern of the adjustable light source **5210** may be controlled so as to move a gamma correction curve **7700***d* closer to the above described conversion line **7700**L (as indicated in the bottom part of FIG. **24**). This is done by increasing the emission intensity of the light source pulse, from the emission light intensity H**0** to the emission light intensity H**1**, toward the tail end of the display period of one frame, as indicated by a light source pulse pattern **7802**, as shown in FIG. **24**.

FIGS. **23** and **24** illustrate a gamma correction by changing the emission intensity while maintaining the adjustable light source **5210** so that it continuously emits light, as indicated by the light source pulse patterns **7801** and **7802**. The control may also be performed by means of an intermittent pulse emission.

FIG. **25**A exemplifies a control by means of the aforementioned intermittent pulse emission. A light source pulse pattern **7803** illustrated in FIG. **25**A generates emission pulses having an emission pulse width tp. This is done intermittently in intervals of emission pulse intervals ti, and the number of emission pulses per unit time is increased by gradually decreasing the emission pulse interval ti between the beginning and end of the display period of one frame, thereby achieving an effect similar to that of the continuous light source pulse patterns **7801** and **7802** described above.

Furthermore, the light source pulse pattern **7804** exemplifies the gradual increase of the emission pulse width tp between the beginning and end of the display period of one frame.

The light source pulse pattern **7805** exemplifies the gradual decrease of the emission pulse intervals ti and also the gradual increase of the emission pulse width tp between the beginning and end of the display period of one frame.

Furthermore, the light source pulse pattern **7806** exemplifies the gradual increase of both the emission pulse width tp and emission light intensity H**2** between the beginning and end of the display period of one frame.

As in the case of the light source pulse patterns **7803**, **7804**, **7805** and **7806**, illustrated in FIG. **25**A, the peak of the drive frequency of the adjustable light source **5210** is distributed by changing the emission pulse widths tp and emission light intensity H**2** within one frame, thereby suppressing the electromagnetic noise from the adjustable light source **5210**.

The following is a description of an exemplary modification of a modulation of pulse emission of the adjustable light source **5210** with reference to FIGS. **25**B, **25**C, **25**D and **25**E. The exemplary modification shows the operations of the modulation states of the pulse emission of the adjustable light source **5210** in such a way that they differ depending on the magnitude of the brightness data of each pixel, i.e., the lengths of the ON period of the mirror **5112** within one frame. As illustrated in FIG. **25**B, this modification uses a pulse emission pattern **7811** that includes a repeated array of emission pulse groups **7811***a* of individual emission pulses, i.e., emission pulse widths R-tp, G-tp and B-tp of R (red light), G (green light) and B (blue light), that are emitted from the adjustable light source **5210** within one frame.

FIG. **25**B shows the emission pulses with equally set each of the emission pulse widths R-tp, G-tp and B-tp, of the respective emission pulses R, G and B, within a plurality of emission pulse groups **7811***a* constituting the pulse emission pattern **7811**. The light source is also controlled to gradually increase the pulse width from the beginning to the end of one frame for each of the individual emission pulse group **7811***a*. Furthermore, the emission light intensity H**10** is constant within one frame in each of the emission pulse-groups **7811***a*. The pulse emission pattern **7812** illustrated in FIG. **25**C shows the case of setting the emission light intensity H**10** constant and setting the emission pulse widths R-tp, G-tp and B-tp at different values within each of the emission pulse groups **7812***a*, thereby changing the light intensity ratios of R, G and B, specifically, changing the color balance.

Furthermore, the pulse emission pattern **7813** illustrated in FIG. **25**D shows the case of setting the ratio of the emission pulse widths R-tp, G-tp and B-tp constant in each of the emission pulse groups **7813***a* within one frame, and gradually increasing the emission light intensity H**10** starting from the beginning to the end of a frame. The pulse emission pattern **7814** illustrated in FIG. **25**E changes so that the emission light intensities H11, H12 and H14 of the respective pulse emission of R, G and B are differ within each of the emission pulse groups **7814**a.

The time sequences of the pulsed emissions described in FIGS. **25**B through **25**E each differentiates the ratios of R, G and B in accordance with a period in which the mirror **5112** is in the ON state within one frame, that is, in accordance with the magnitude of the non-binary data **7705** that is brightness data. Thus, the color balance is controlled in accordance with the brightness of each pixel. This means that when a discretionary pixel is made to be, for example, red, a control for changing the tone of the red in accordance with the brightness of the present pixel is attained. Therefore, the light source can freely control a tone in such a manner so that, for example, black (i.e., the minimum brightness) will be displayed blacker; white (i.e., the maximum brightness) will be changed to, for example, a bluish color. Meanwhile, the spectral luminous efficiency of the human eye is known to differ depending on the brightness and the color of light, and therefore, the present embodiment is configured to achieve the optimal color balance, in consideration of the visual perception of the human eye, by changing the color balance in accordance with the brightness to attain a best spectral luminous efficiency of the human eyes.

FIGS. **26**A and **26**B illustrate a gamma correction curve **7700**e performing a gamma correction to more effectively correct the lower brightness side by means of a light source pulse pattern **7807**.

The light source pulse pattern **7807** shown in FIG. **26**A controls the emission pattern of the adjustable light source **5210** to generate a plurality of emission pulses. These pulses have a constant emission pulse width tp with a small emission pulse interval on the start side (i.e., the lower density side) of the display period and gradually decrease in the number of pulses (specifically, the emission pulse interval ti gradually increases) towards the end of the display period. This control process makes it possible to attain a gamma correction curve **7700**e which is convex-shaped toward the top-left of the conversion line **7700**L and which, accordingly, provides a effective correction, i.e., increasing brightness, on the lower brightness side, as illustrated in FIG. **26**B.

FIGS. **27**A and **27**B illustrate a gamma correction with consideration given to human vision. This is done by a control of the adjustable light source **5210** with a light source pulse pattern **7808**.

The human eye is highly sensitive to light in the mid-range of low and high brightness. Accordingly, the gamma correction is performed by controlling the adjustable light source **5210** with the light source pulse pattern **7808** which 1.) Causes emission pulses to have the same emission pulse width tp with a small emission pulse interval ti at the center of the display period of one frame and 2.) FIG. **27**A shows a gradual decrease of the density of the emission pulse toward either side.

This control achieves a gamma correction using a gamma correction curve **7700**f that is smaller than the conversion line **7700**L on the lower brightness side and larger than that on the higher brightness side, thereby making it possible to obtain a modulated and clear projection image, i.e., darker on low brightness side and brighter on high brightness side.

Note that the present patent application has disclosed specific preferred embodiments of the present invention. However, various modifications and changes may be applied to these embodiments within the scope and/or concept of the present invention. Therefore, the present patent application and figures shall be construed as specific embodiment instead of being limited to these particular descriptions.

The present invention provides a technique to achieve an accurate modulation light intensity without being influenced by the transition between the ON state and OFF state in the ON/OFF modulation of a mirror.

The present invention also provides a technique to achieve control of a modulation light intensity independent of the speed of the tilt control of a mirror.

The present invention further provides a technique of controlling a color temperature and a color balance without requiring a change in the inputted video image signal.

Although the present invention has been described in terms of the presently preferred embodiment, it is to be understood that such disclosure is not to be interpreted as limiting. Various alternations and modifications will no doubt become apparent to those skilled in the art after reading the above disclosure. Accordingly, it is intended that the appended claims be interpreted as covering all alternations and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A display apparatus, comprising:

a light source or light sources for emitting a light of a plurality of colors;

a spatial light modulator comprises a plurality of pixel elements for modulating the light for projecting an image; and

a controller for processing inputted video image data and controlling the light source and the spatial light modulator, wherein

said controller controls the light source by applying a light source pulse pattern to emit the light having at least two colors as discrete pulses according to said light source pulse pattern controllable to have a pulse width shorter than a modulating period represented by a least significant bit (LSB) of a word of the inputted video image data in controlling and modulating each of the pixel elements of the spatial light modulator (SLM).

2. The display apparatus according to claim **1**, wherein:

the controller applies the light source pulse pattern to increase an emission time length of a main color in a sub-field of a display frame period and to decrease the emission time length of other colors shorter than the modulation period for controlling the SLM.

3. The display apparatus according to claim **1**, wherein:

the controller applies the light source pulse pattern to increase a main color emission time length of a main color in a sub-field of a display frame period wherein the main color emission time length is greater than the emission time length of other colors shorter than the modulation period for controlling the SLM.

4. The display apparatus according to claim **1**, wherein:

the light source further comprises a light emitting diode (LED) or a laser light source.

5. The display apparatus according to claim **1**, wherein:

the controller further generates control signals by applying the inputted video image data to control each of the pixel elements of said spatial light modulator to operate each of the pixel elements under a plurality of modulation states.

6. The display apparatus according to claim **1**, further comprising:

a projector, wherein

each of the pixel elements of the spatial light modulator comprising a mirror element including a micromirror, and

the projector projects the image comprises image pixels reflected and modulated by each of the mirror elements of the spatial light modulator.

7. The display apparatus according to claim **6**, wherein:
the controller applies the control signals to control the micromirror in each of the mirror elements of the spatial light modulator to operate in an ON state for reflecting and modulating the light emitted from the light source to the projector, or an OFF state for guiding the light emitted from the light source away from the projector or an oscillation state between the ON state and OFF state.

8. The display apparatus according to claim **1**, wherein:
the controller converts said inputted video data comprising binary video data into a non-binary video data, and
the controllers applies control signals generated from the non-binary data to control each of the pixel elements of the spatial light modulator.

9. The display apparatus according to claim **1**, wherein:
the controller controls the light source to emit at least two lights of different colors as the discrete pulses of at least two different pulse widths wherein the two different pulse widths are shorter than the modulating period represented by the least significant bit (LSB) of a word of the inputted video image data for controlling each of the pixel elements of the SLM.

10. The display apparatus according to claim **1**, wherein:
the controller controls the light source to emit at least two lights of different colors as the discrete pulses of at least two different pulse intensities wherein the discrete pulses having the pulse widths shorter than the modulating period represented by the least significant bit (LSB) of a word of the inputted video image data for controlling each of the pixel elements of the SLM.

11. The display apparatus according to claim **1**, wherein:
the controller controls the discrete pulses emitted from the light source for adjusting a color balance for each of the pixel elements for displaying each image pixel of the image.

12. The display apparatus according to claim **1**, further comprising:
a video image analyzer for analyzing the brightness of each color of the inputted image data, wherein
the controller controls the discrete pulses emitted from the light source for adjusting a color balance for each of the pixel elements in accordance with a control signal from the video image analyzer.

13. The display apparatus according to claim **11**, wherein:
the controller controls the light sources to emit one of the discrete pulses as a first discrete pulse in a time when a brightness data of each pixel is dark and to emit another one of the discrete pulses as a second discrete pulse when the brightness data of each pixel is bright and wherein the first discrete pulse is different from the second discrete pulse.

14. The display apparatus according to claim **11** wherein:
each of the pixel elements of the spatial light modulator further comprises a micromirror, and
the controller further applies a brightness data to control the light source to repeatedly project sets of sequential emissions of different colors for a plurality of times by changing at least either pulse widths or pulse intensities of the pulse emissions with each of said pulse widths shorter than a length of time when each of the micromirrors is operated in one mirror state.

15. The display apparatus according to claim **14**, wherein:
the controller further controls the light source to keep a constant ratio of the light intensities of the different colors within each set of the sequential emissions.

16. The display apparatus according to claim **14**, wherein:
the controller further controls the light source to control an adjustable ratio of light intensities of the different colors within each set of the sequential emissions.

17. A display apparatus, comprising:
a light source for emitting a light of a plurality of colors;
a spatial light modulator comprises a plurality of pixel elements for modulating the light; and
a controller for controlling the light source and the spatial light modulator according to an input image signal, wherein the light source is controlled to emit at least two pulse emissions with at least two different colors according to a light source pulse pattern controllable to have a pulse width shorter than a modulating period of the spatial light modulator represented by a least significant bit (LSB) of a word of the input image signal for controlling and modulating each of the pixel elements of the spatial light modulator.

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